(12) UK Patent Application (19) GB (11) 2 372 656 (13) A

(43) Date of A Publication 28.08.2002

(21) Application No 0104456.9

(22) Date of Filing 23.02.2001

(71) Applicant(s)
Industrial Control Systems Limited
(Incorporated in the United Kingdom)
4 Cockshutt Drive, Greenhill, SHEFFIELD, S8 7DW, United Kingdom

(72) Inventor(s)
John Michael Petty
Phillip Stephen Petty

(74) Agent and/or Address for Service
Franks & Co
9 President Buildings, Savile Street East, SHEFFIELD, S4 7UQ, United Kingdom

(51) INT CL[7]
G01S 17/46

(52) UK CL (Edition T)
H4D DLRA D23X D234 D265 D710 D733 D745 D747 D748 D752 D757 D773 D775 D782 D783

(56) Documents Cited
EP 0224237 A1 **EP 0145957 A1**
US 5915033 A1

(58) Field of Search
UK CL (Edition S) **G1A AAJL , H4D DLAT DLM DLPC DLPX DLRA**
INT CL[7] **G01C 3/08 3/10 , G01S 7/491 17/46**

(54) Abstract Title
Optical position determination

(57) An optical rangefinder projects a number of beams of light onto a target surface in a preset pattern. This is viewed by a camera having a CCD or CMOS sensor array, and from the positions of the reflected light on the sensor array the orientation of the camera array relative to the target surface is determined. This is used to determine the position of the surface accurately.

The colour of the light beams may be used to identify reflected light.

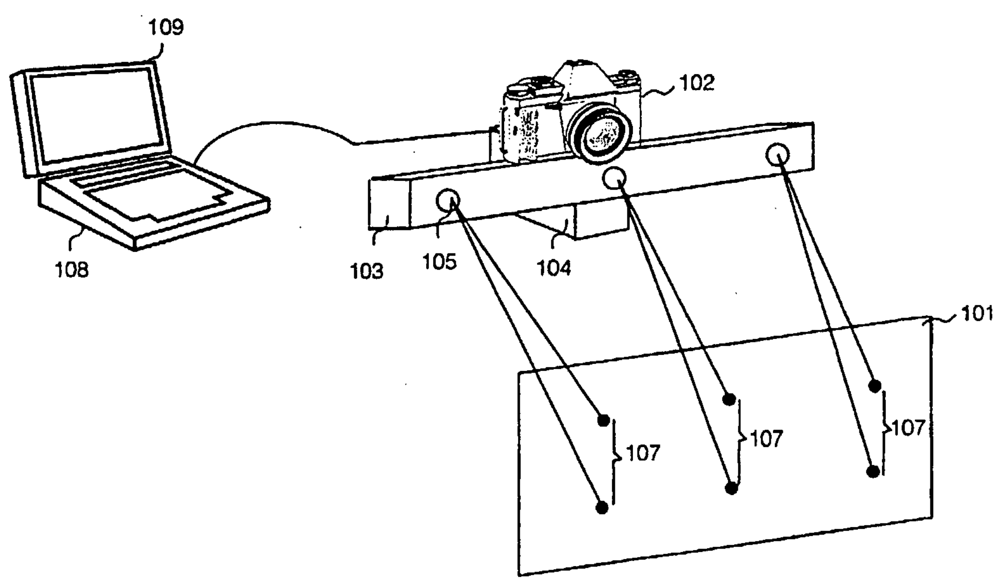


Fig. 1

GB 2 372 656

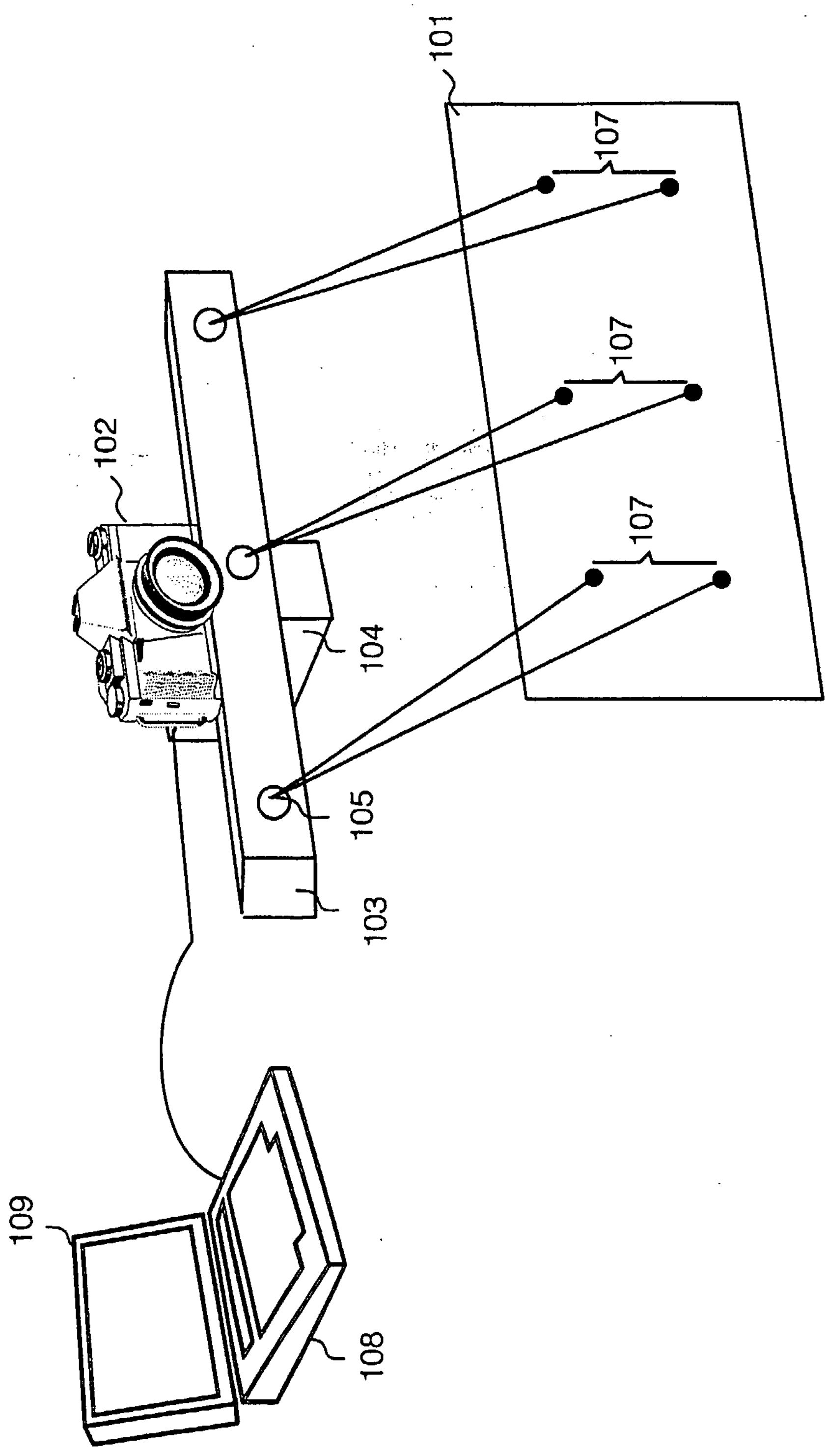


Fig. 1

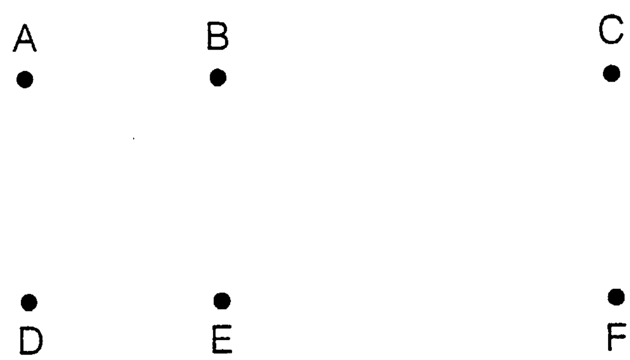


Fig. 2a

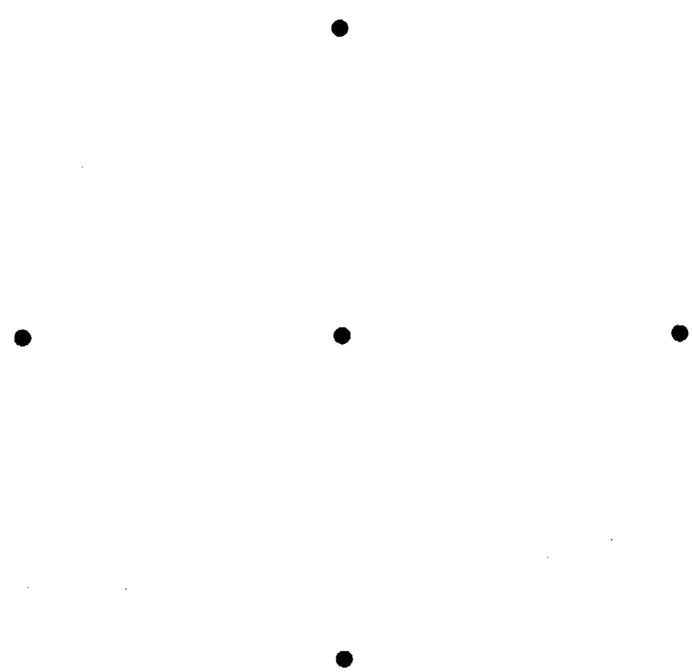


Fig. 2b

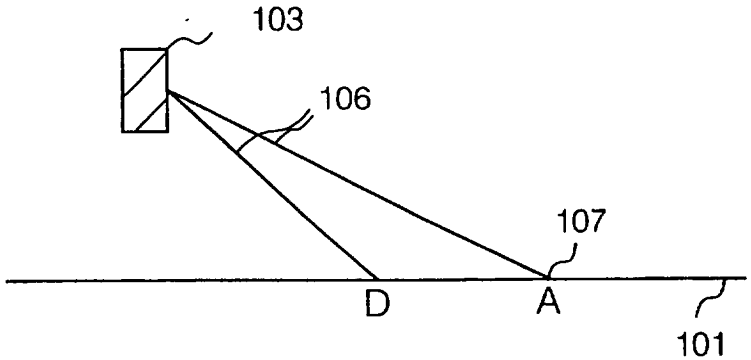


Fig. 3a

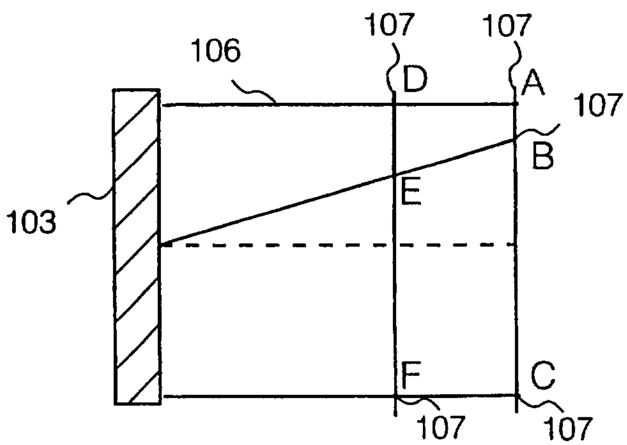


Fig. 3b

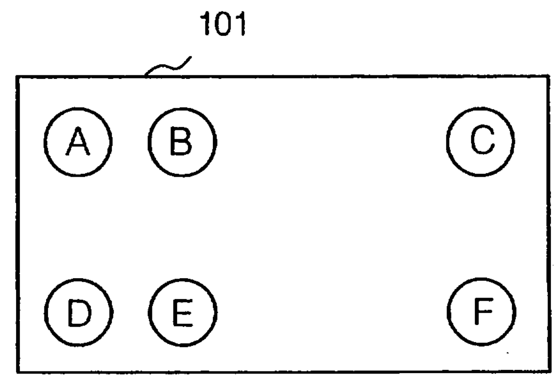


Fig. 3c

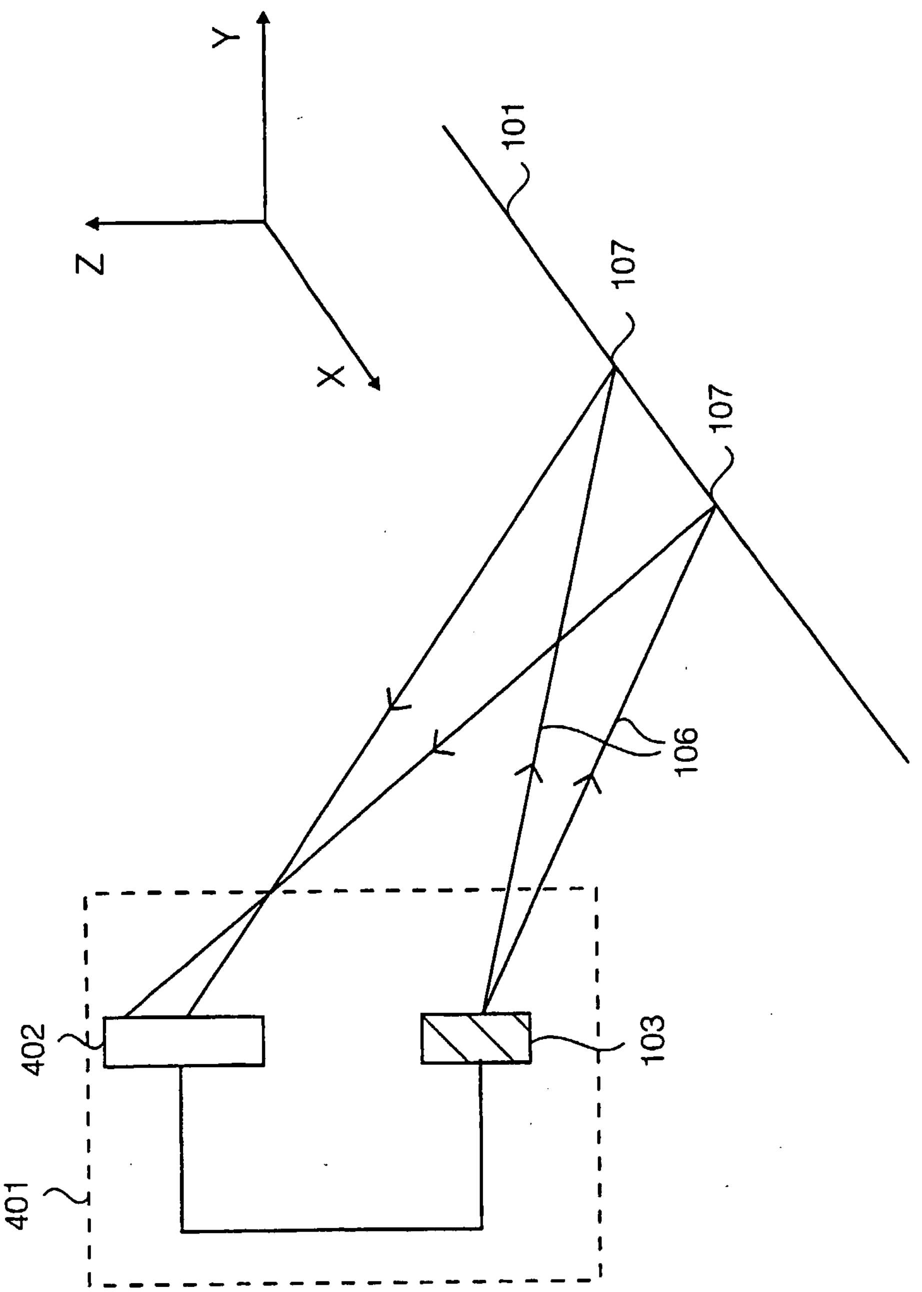


Fig. 4

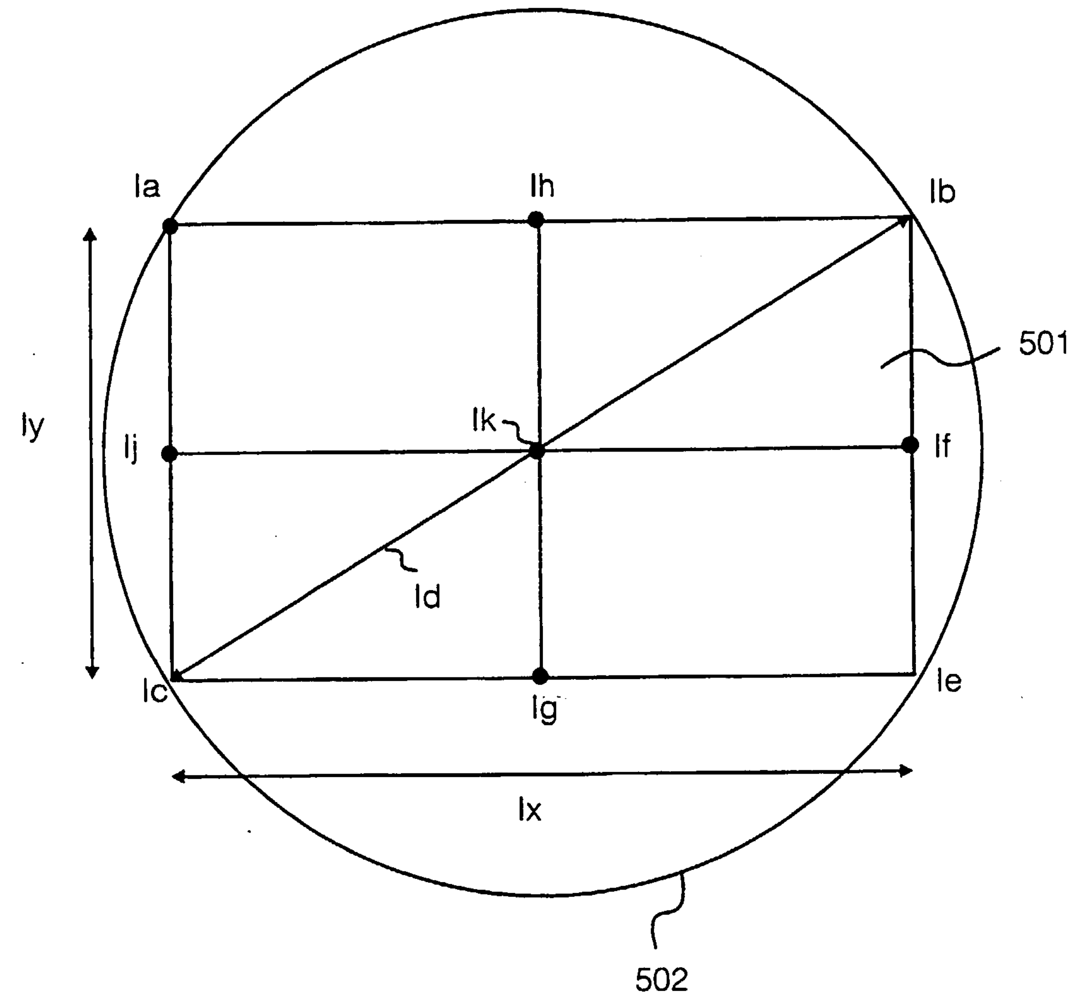


Fig. 5

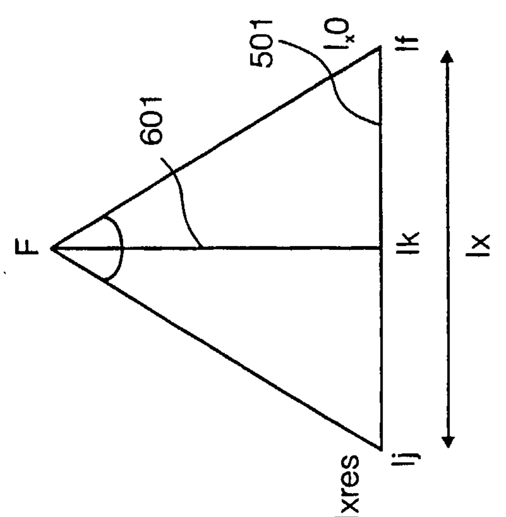


Fig. 6a

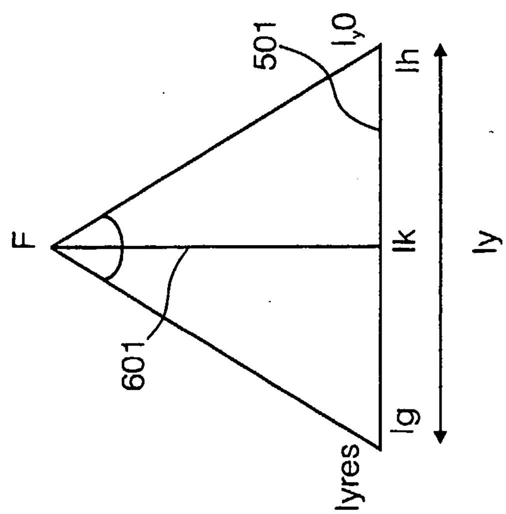


Fig. 6b

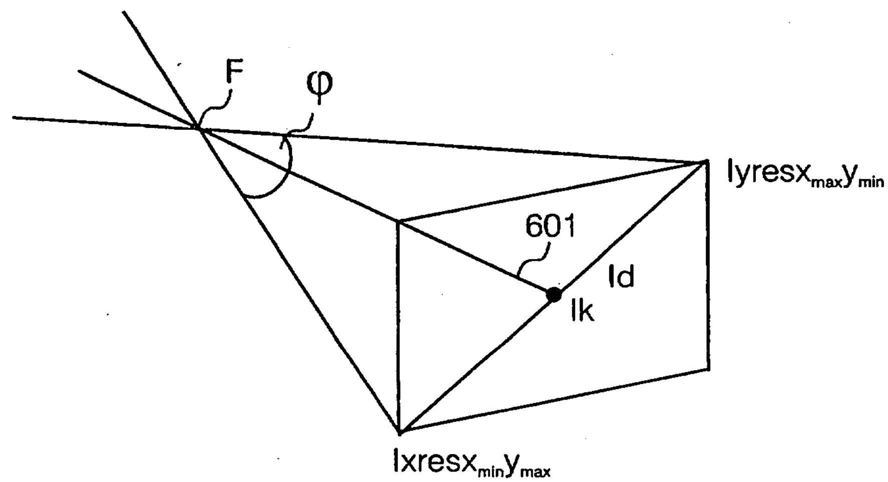


Fig. 7

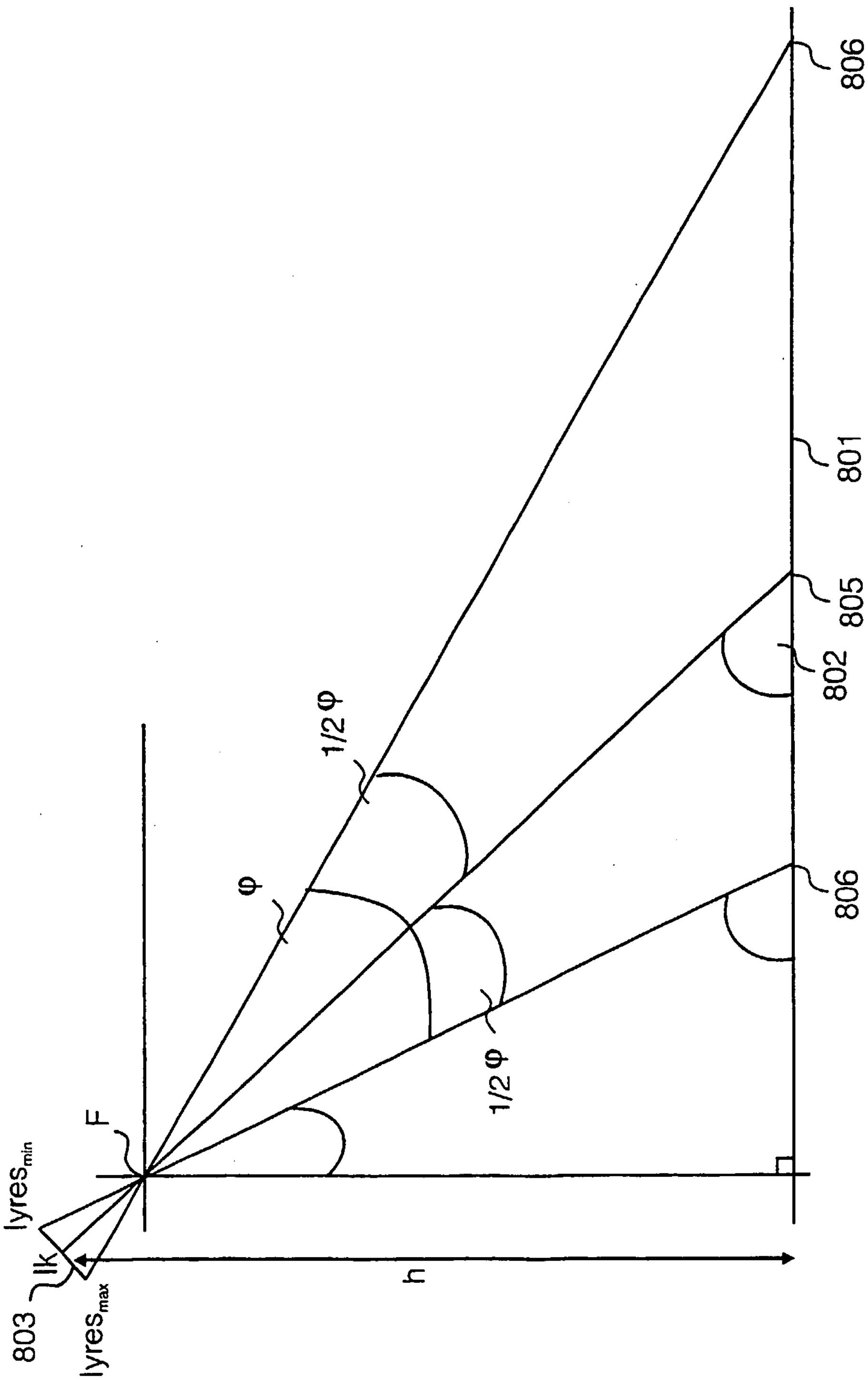


Fig. 8

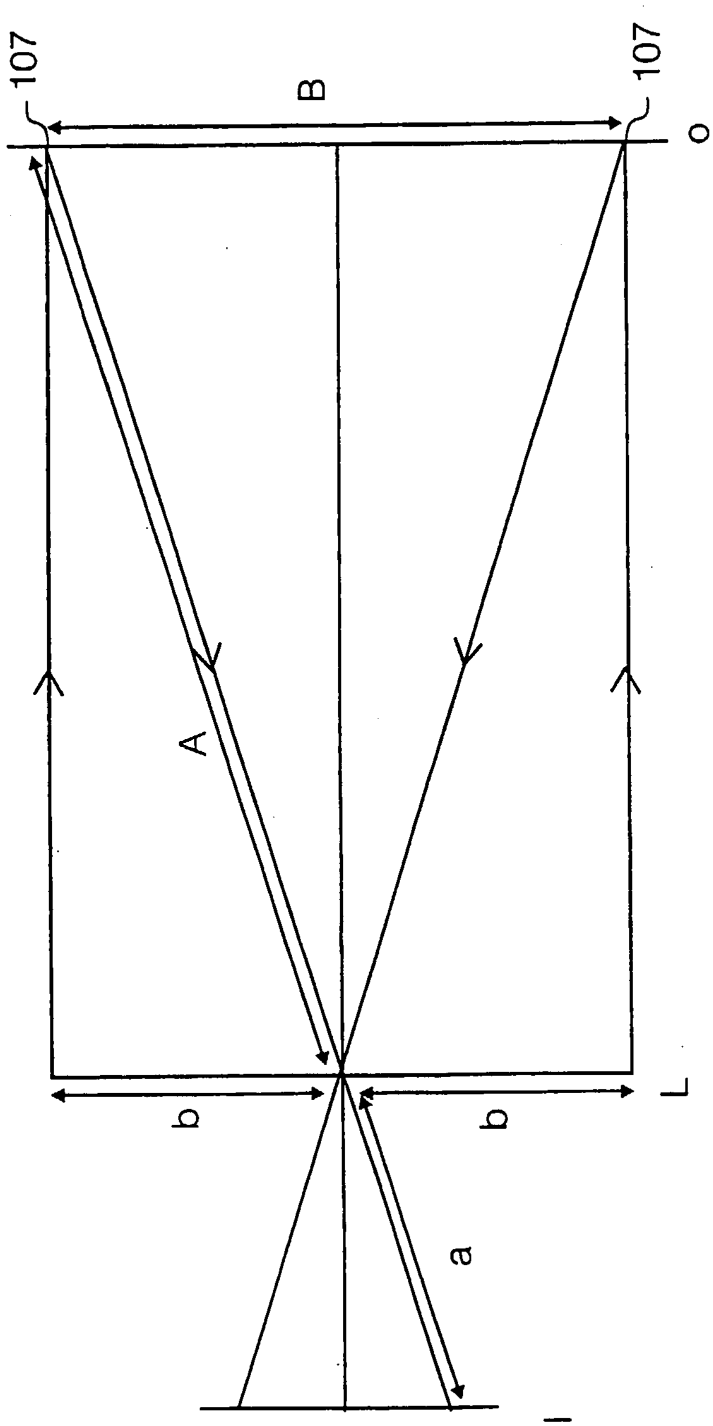


Fig. 9

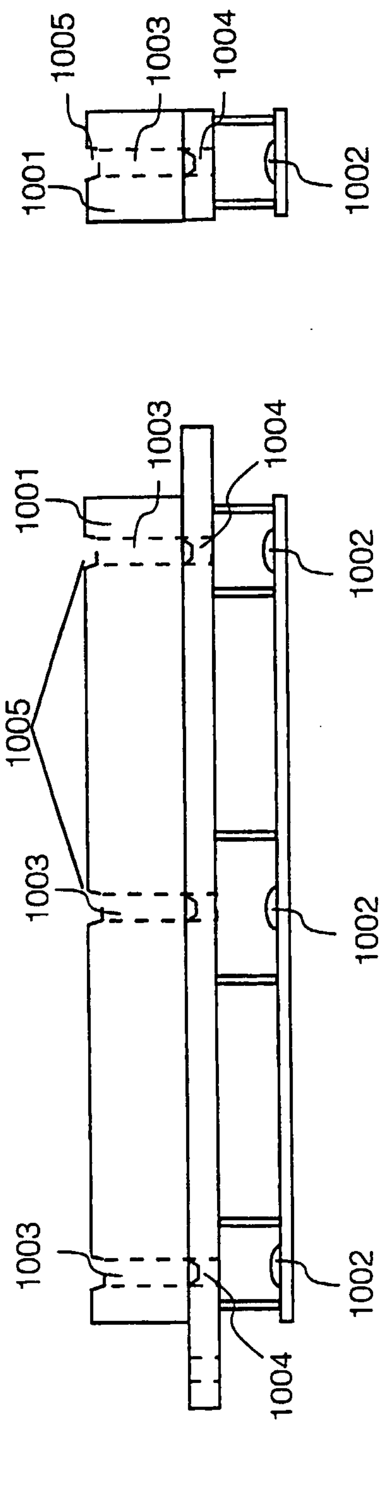

1001
1005
1003
1004
1002
1001
1003
1004
1002
1005
1003
1002
1003
1002
1004

Fig. 10

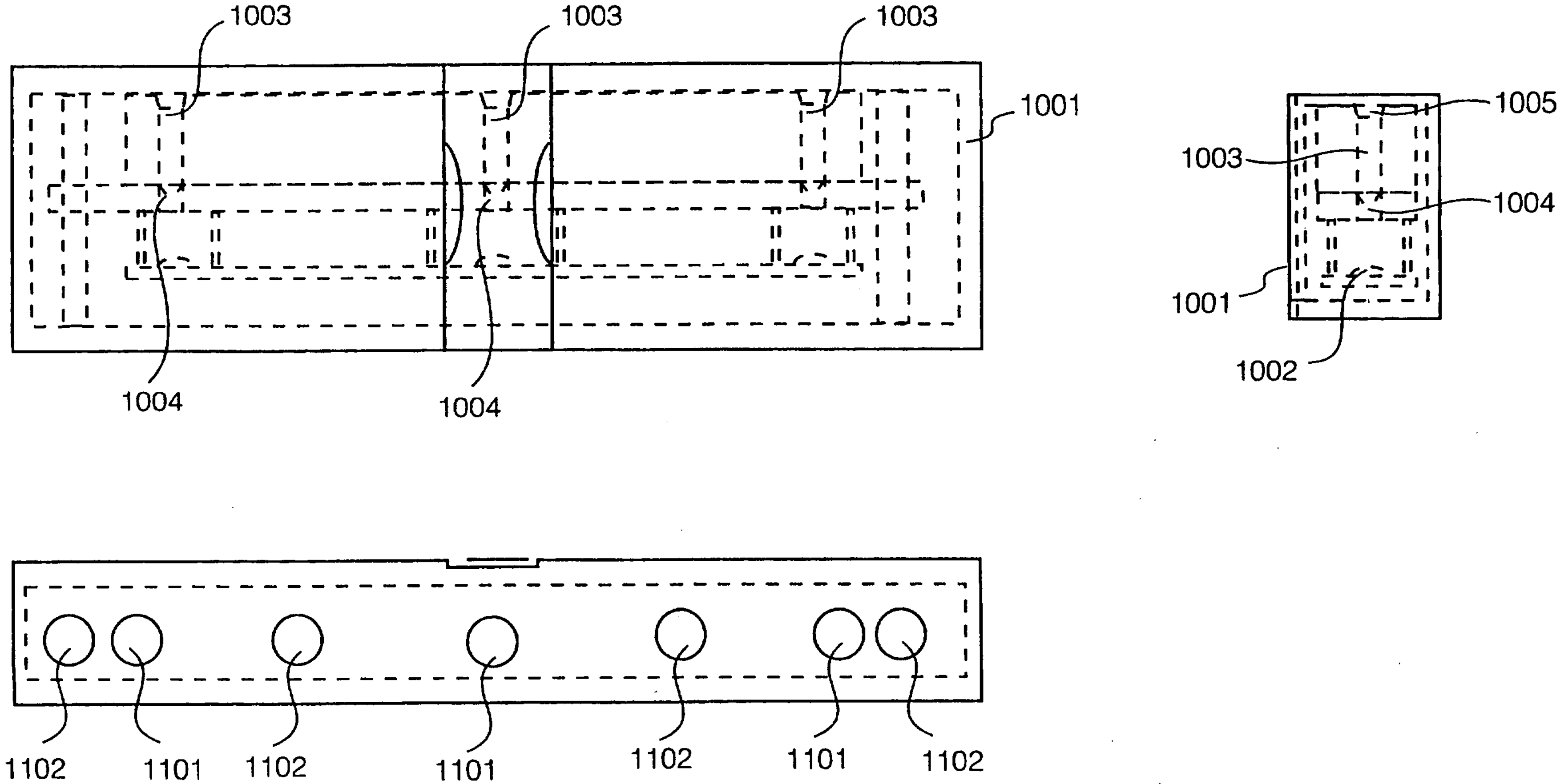

1003
1003
1003
1001
1004
1004
1005
1003
1004
1001
1002
1102
1101
1102
1101
1102
1101
1102

Fig. 11

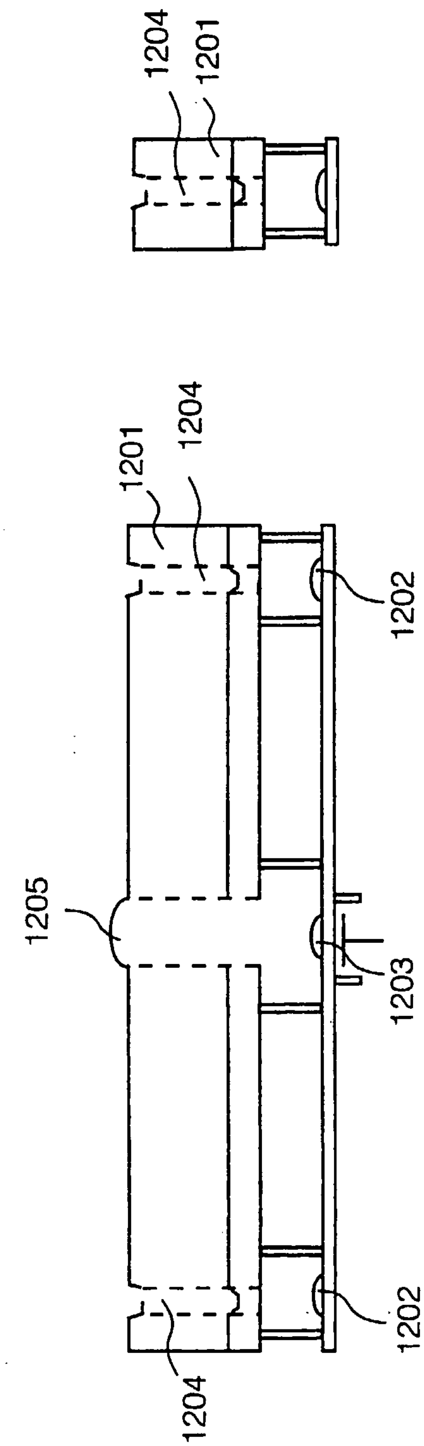


Fig. 12

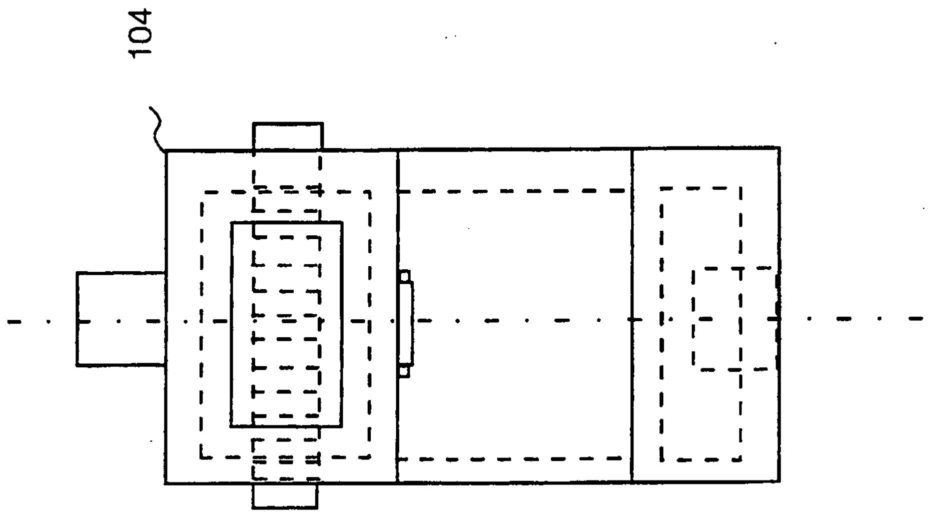


Fig. 13b

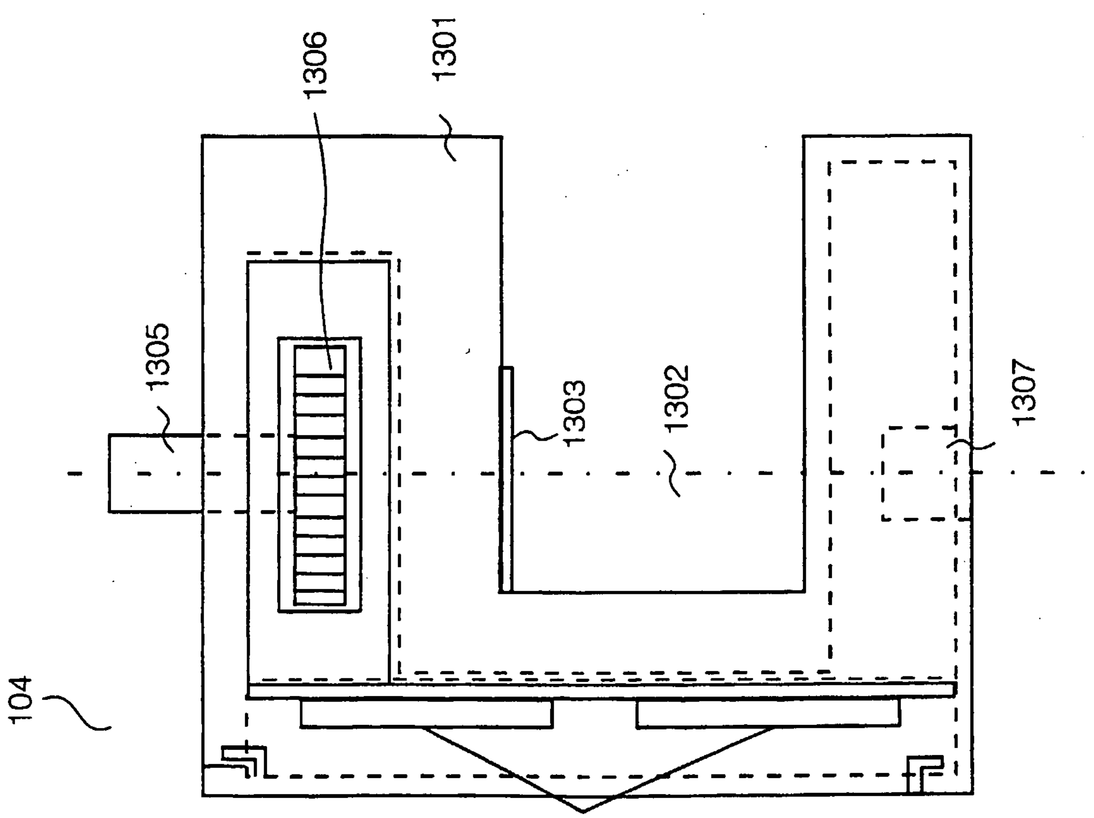


Fig. 13a

Table 1

Laser Specification	
Laser wavelength (nm)	635 - 680
Beam deflection (millirads/m)	0.5
Collimated lens divergence (mm/m)	0.546

Fig. 14

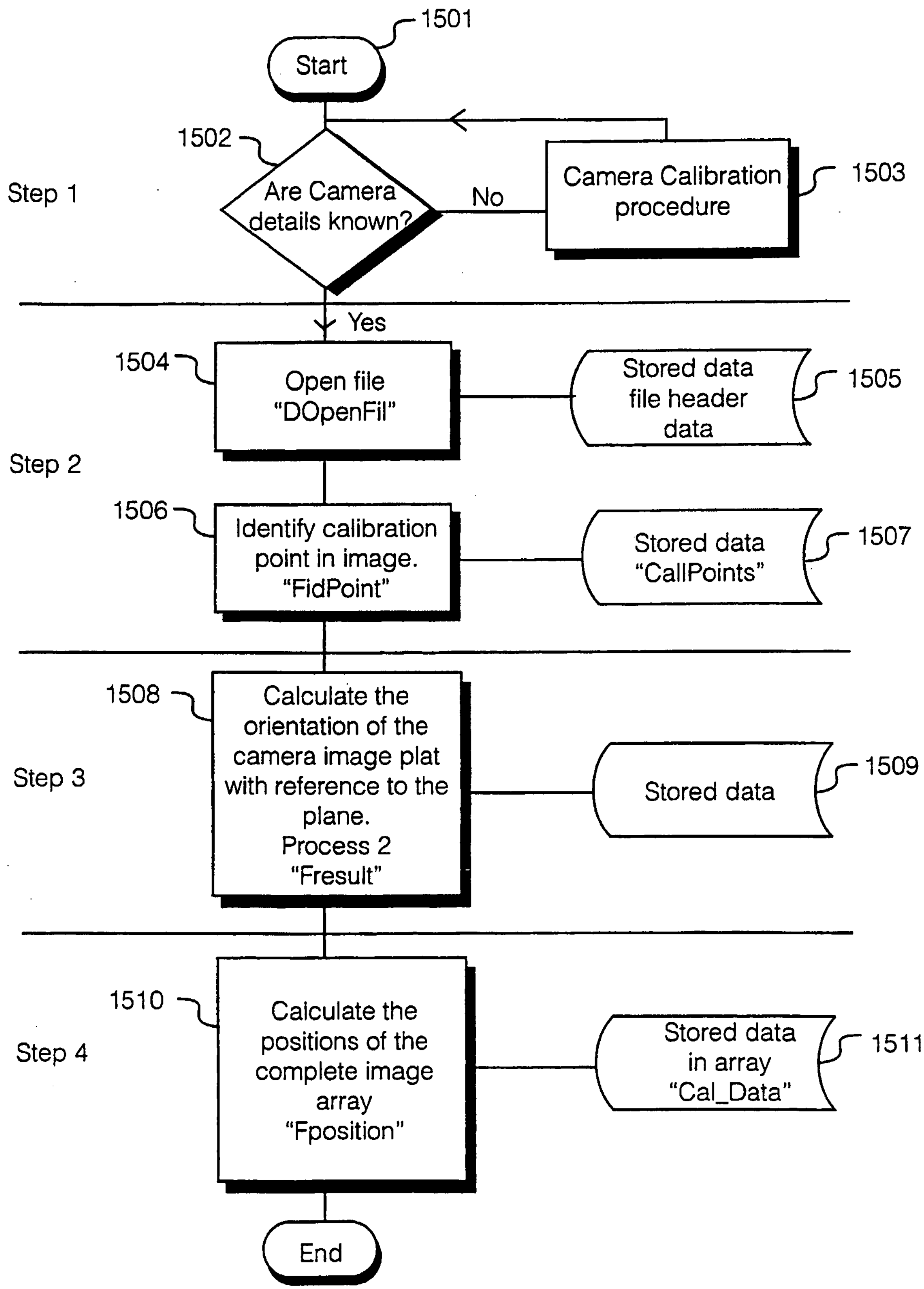

1501
Start
1502
Are Camera details known?
No
Camera Calibration procedure
1503
Step 1
Yes
1504
Open file "DOpenFil"
Stored data file header data
1505
Step 2
1506
Identify calibration point in image. "FidPoint"
Stored data "CallPoints"
1507
1508
Calculate the orientation of the camera image plat with reference to the plane. Process 2 "Fresult"
Step 3
Stored data
1509
1510
Step 4
Calculate the positions of the complete image array "Fposition"
Stored data in array "Cal_Data"
1511
End

Fig. 15

Table 2

Sample Camera Manufacturer's Information	
Model	Digital Camber Fuji DX10
Sensor Array	1/3 inch CCD square pixel array, full read format
Image Quality	1,024 x 768 pixels/640 x 480 pixels
File Format	JPEG
Lens	Fujinon fixed-focus F4/F8
Focal Length	f = 5.5mm

Fig. 16

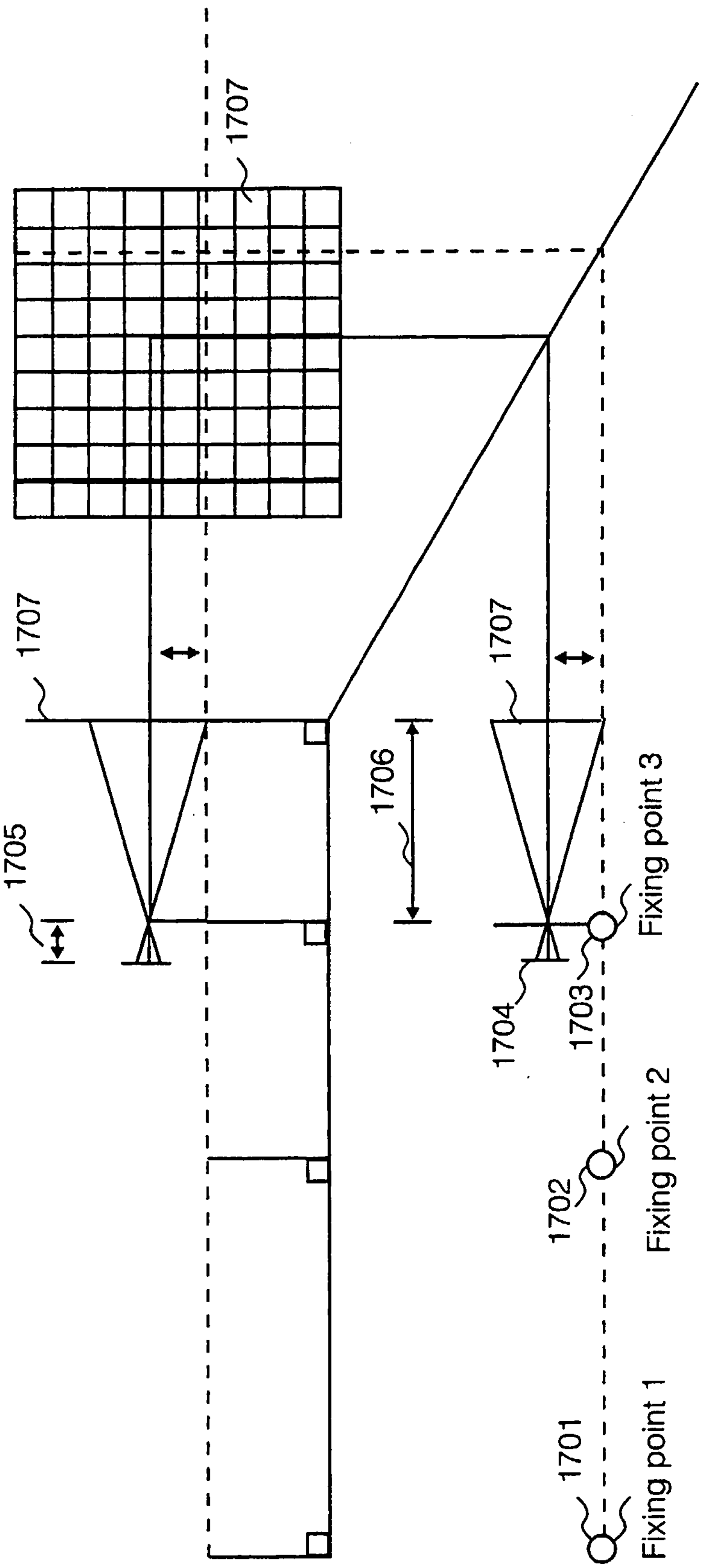

1707
1707
1707
1705
1706
1704
1703
1702
1701
Fixing point 3
Fixing point 2
Fixing point 1

Fig. 17

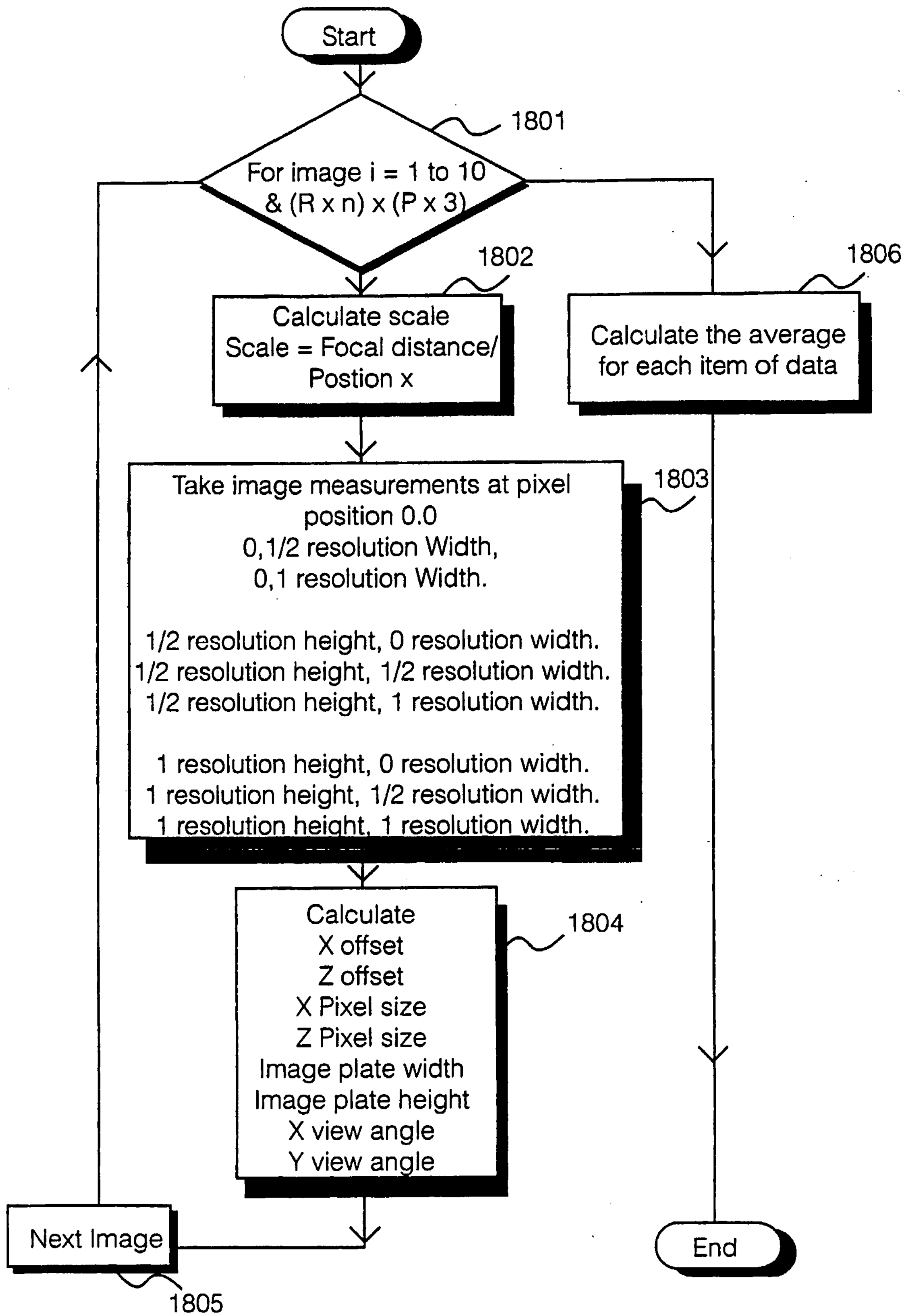

Start
For image i = 1 to 10
& (R x n) x (P x 3)
1801
Calculate scale
Scale = Focal distance/
Postion x
1802
Calculate the average
for each item of data
1806
Take image measurements at pixel
position 0.0
0,1/2 resolution Width,
0,1 resolution Width.
1/2 resolution height, 0 resolution width.
1/2 resolution height, 1/2 resolution width.
1/2 resolution height, 1 resolution width.
1 resolution height, 0 resolution width.
1 resolution height, 1/2 resolution width.
1 resolution height, 1 resolution width.
1803
Calculate
X offset
Z offset
X Pixel size
Z Pixel size
Image plate width
Image plate height
X view angle
Y view angle
1804
Next Image
1805
End

Fig. 18

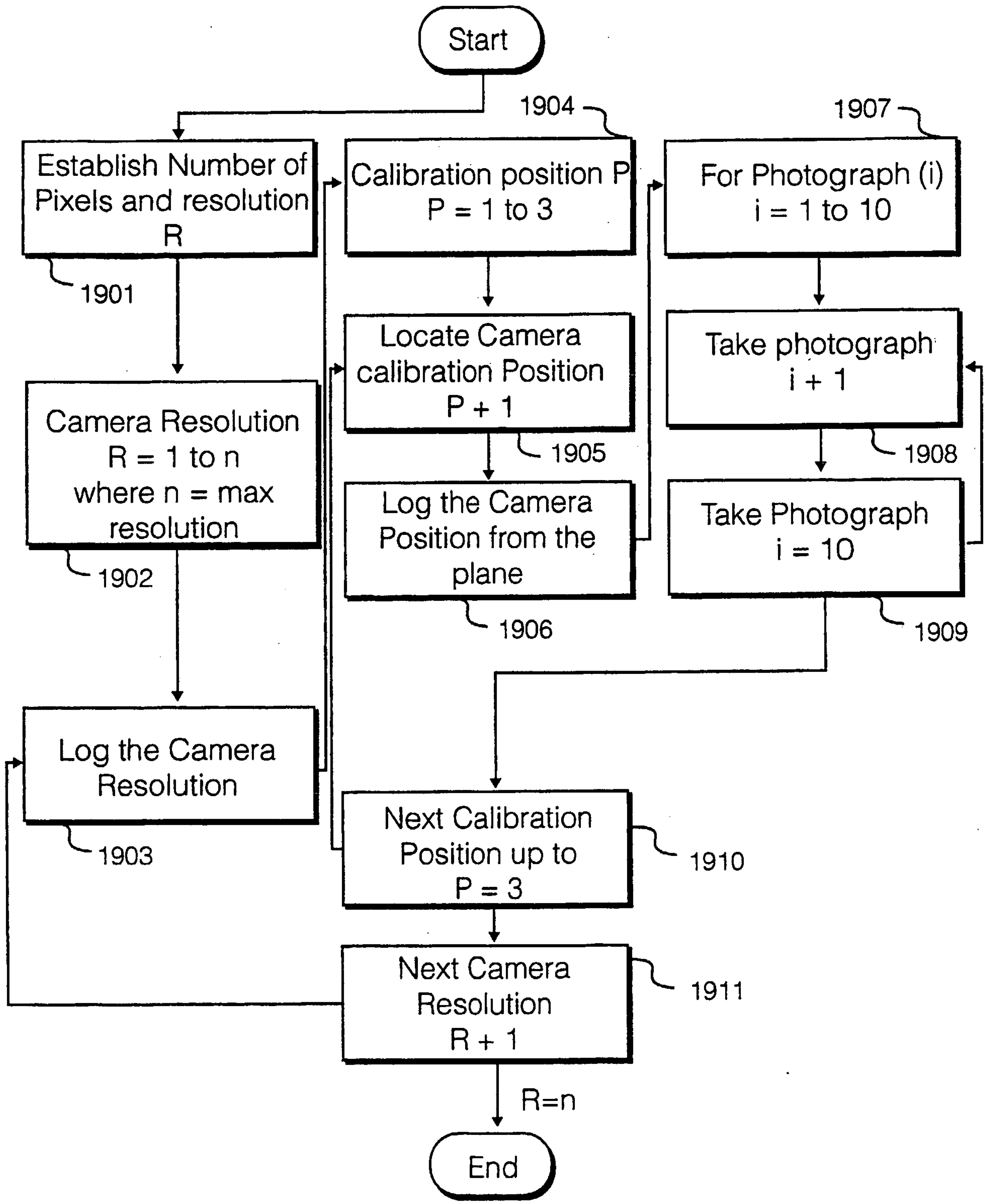

Start
Establish Number of Pixels and resolution R
1901
Camera Resolution R = 1 to n where n = max resolution
1902
Log the Camera Resolution
1903
1904
Calibration position P P = 1 to 3
Locate Camera calibration Position P + 1
1905
Log the Camera Position from the plane
1906
1907
For Photograph (i) i = 1 to 10
Take photograph i + 1
1908
Take Photograph i = 10
1909
Next Calibration Position up to P = 3
1910
Next Camera Resolution R + 1
1911
R=n
End

Fig. 19

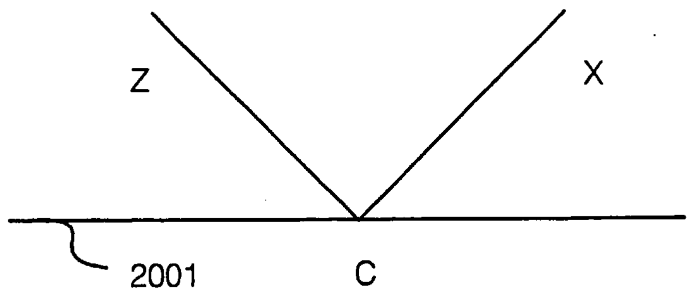


Fig. 20a

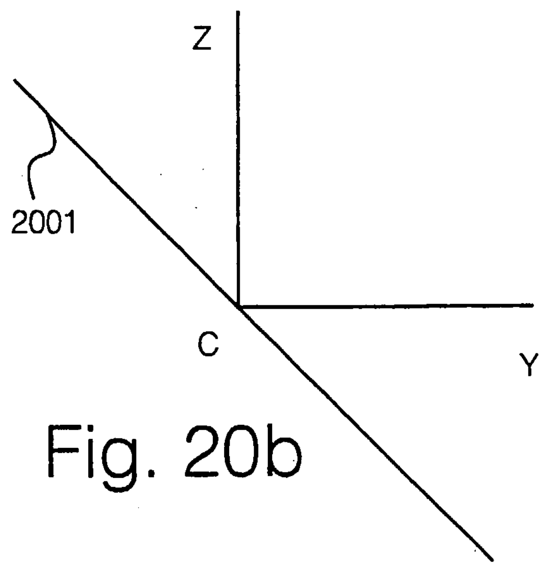


Fig. 20b

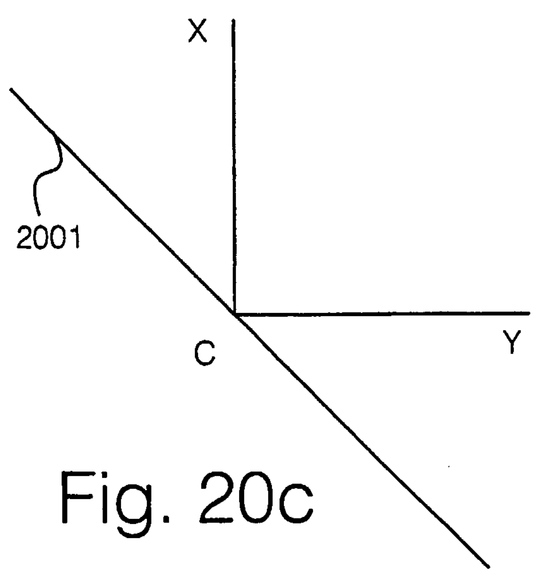
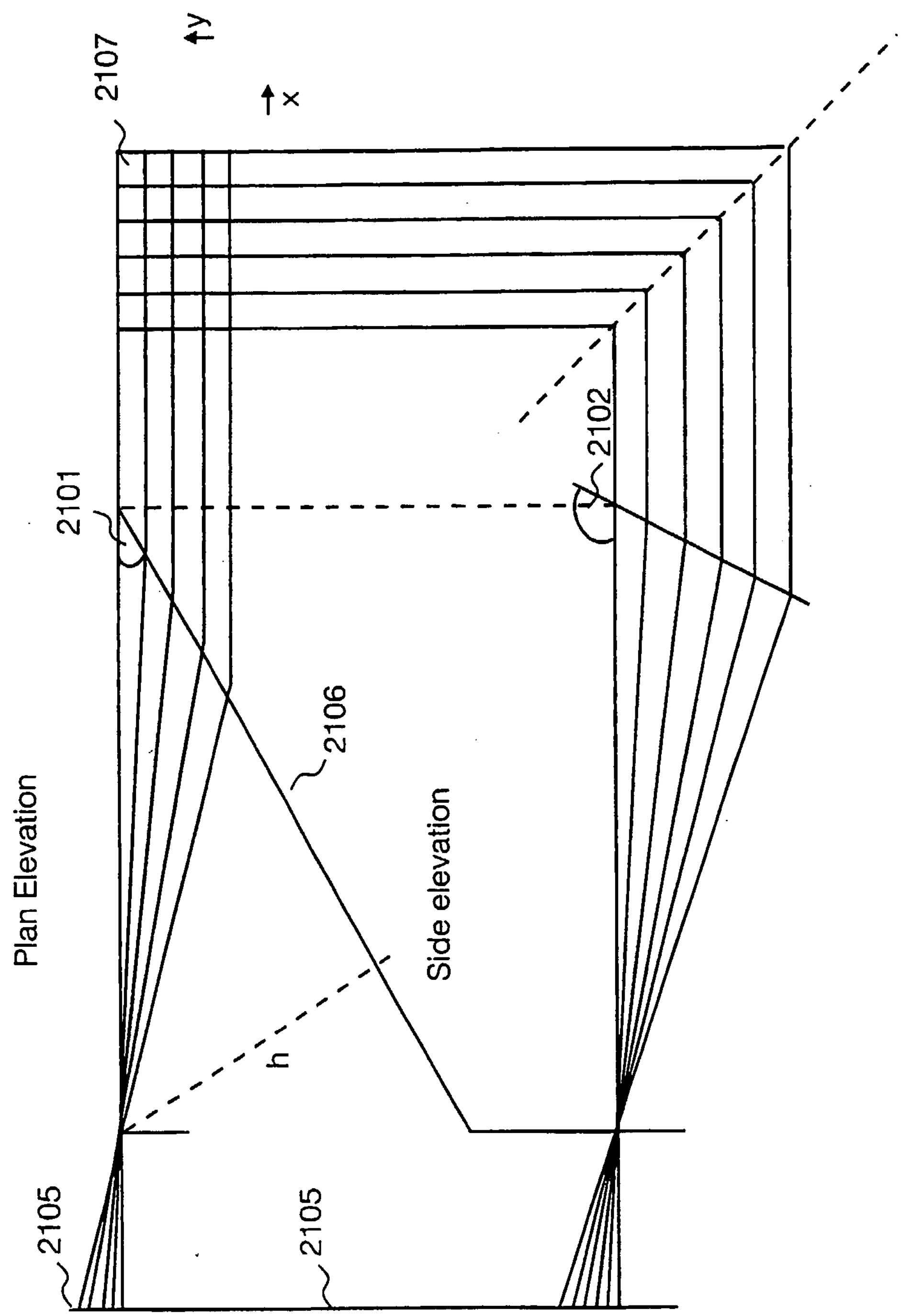


Fig. 20c



2107
y
x
2101
2102
2106
Plan Elevation
Side elevation
h
2105
2105

Fig. 21

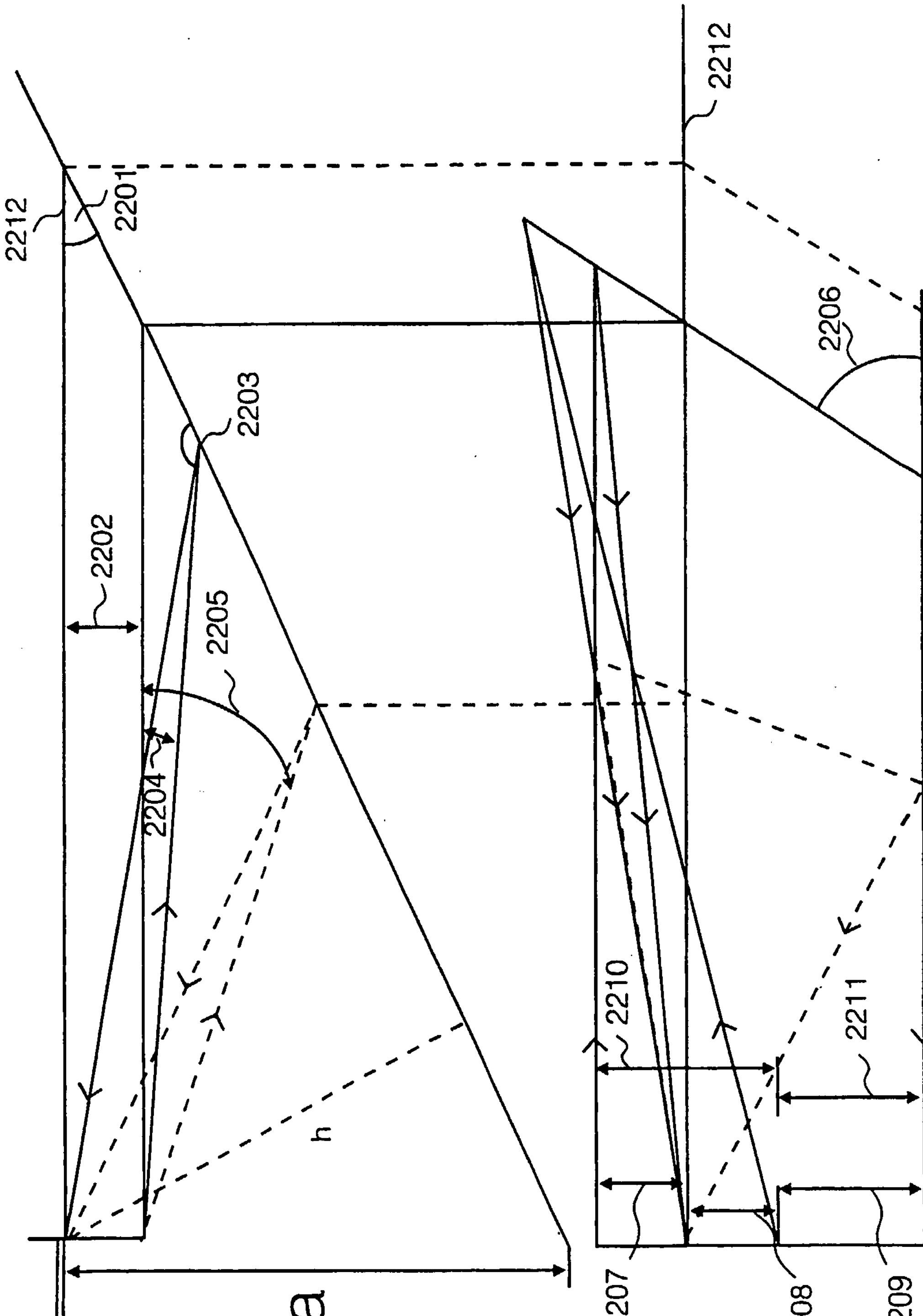


Fig. 22a

Fig. 22b

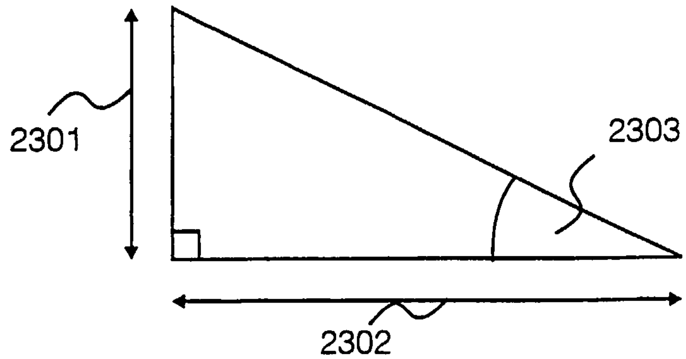


Fig. 23a

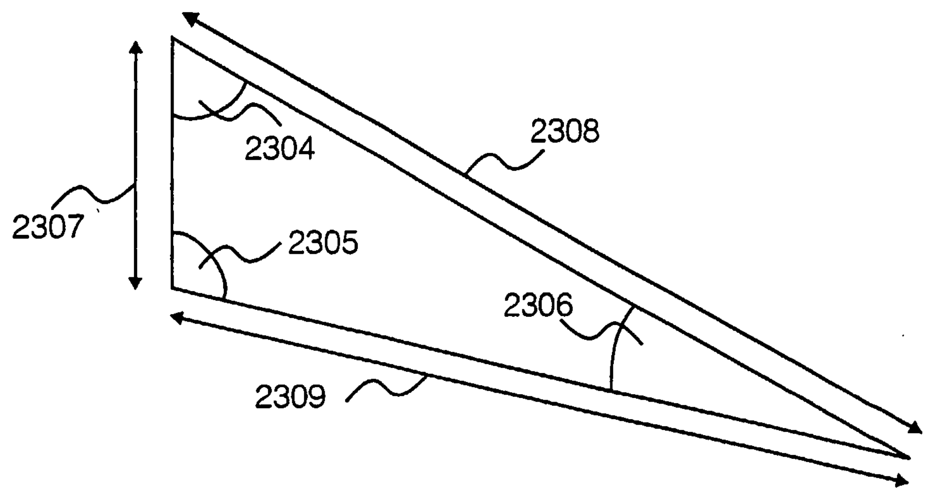


Fig. 23b

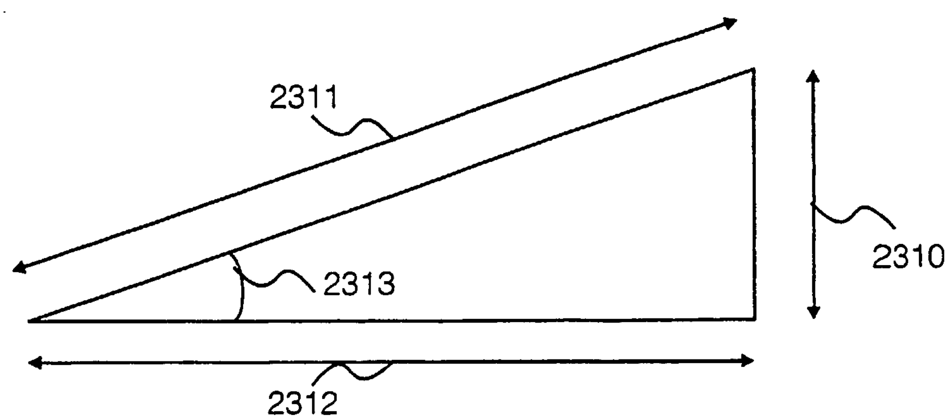


Fig. 23c

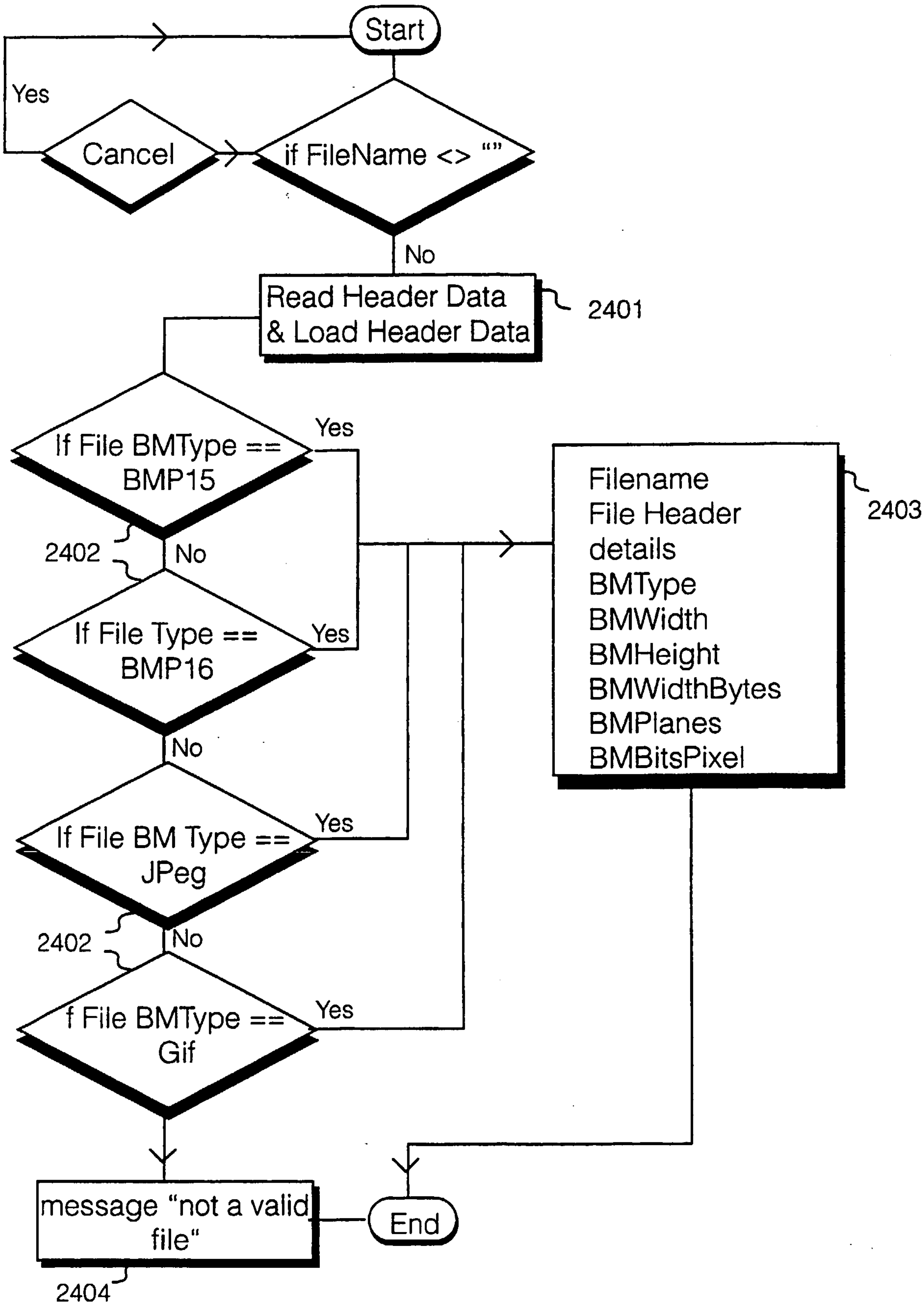

Start
Yes
Cancel
if FileName <> ""
No
Read Header Data
& Load Header Data
2401
If File BMType ==
BMP15
Yes
2402
No
If File Type ==
BMP16
Yes
No
If File BM Type ==
JPeg
Yes
2402
No
f File BMType ==
Gif
Yes
Filename
File Header
details
BMType
BMWidth
BMHeight
BMWidthBytes
BMPlanes
BMBitsPixel
2403
message "not a valid
file"
2404
End

Fig. 24

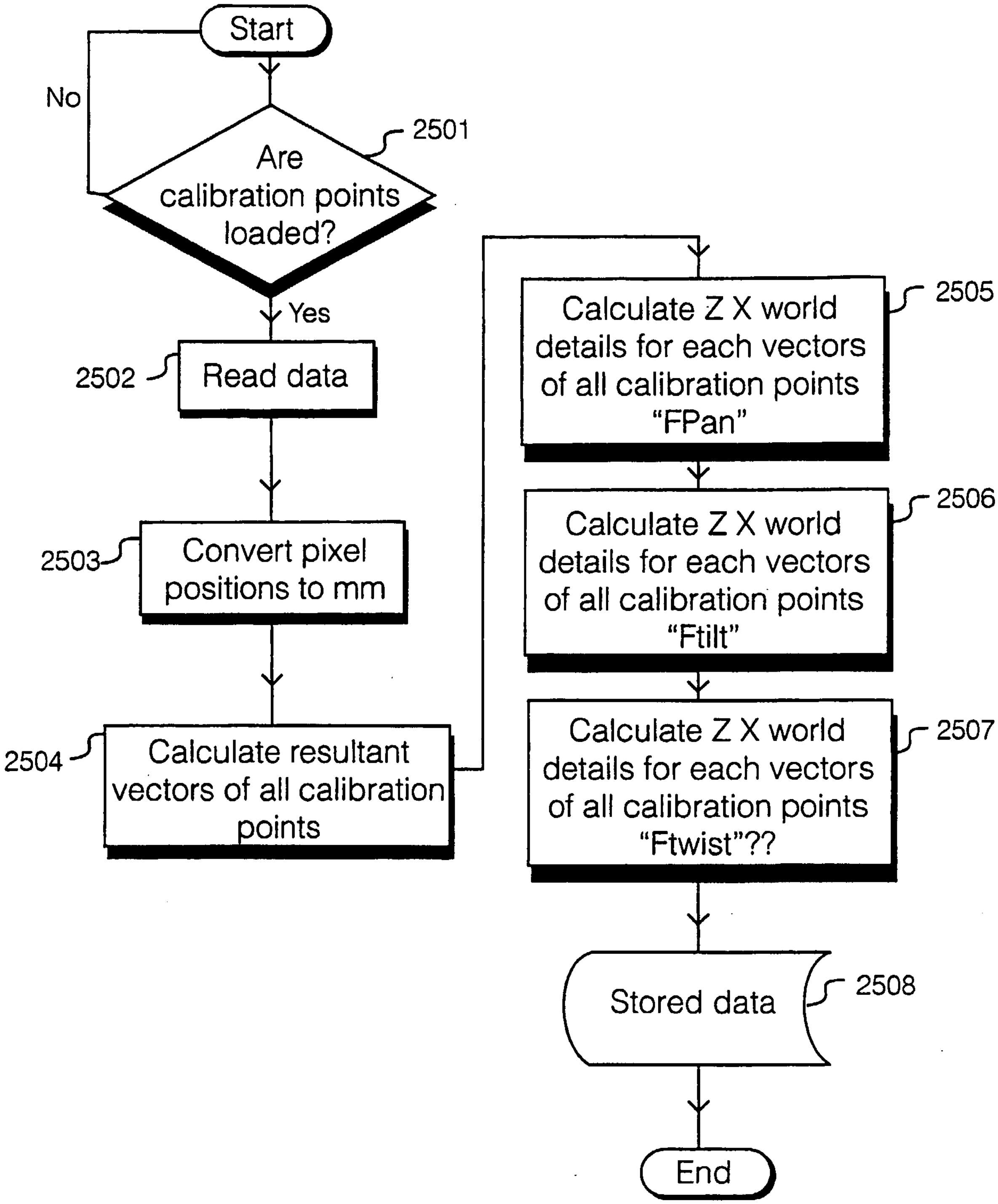

Start
No
Are calibration points loaded?
2501
Yes
2502
Read data
2503
Convert pixel positions to mm
2504
Calculate resultant vectors of all calibration points
Calculate Z X world details for each vectors of all calibration points "FPan"
2505
Calculate Z X world details for each vectors of all calibration points "Ftilt"
2506
Calculate Z X world details for each vectors of all calibration points "Ftwist"??
2507
Stored data
2508
End

Fig. 25

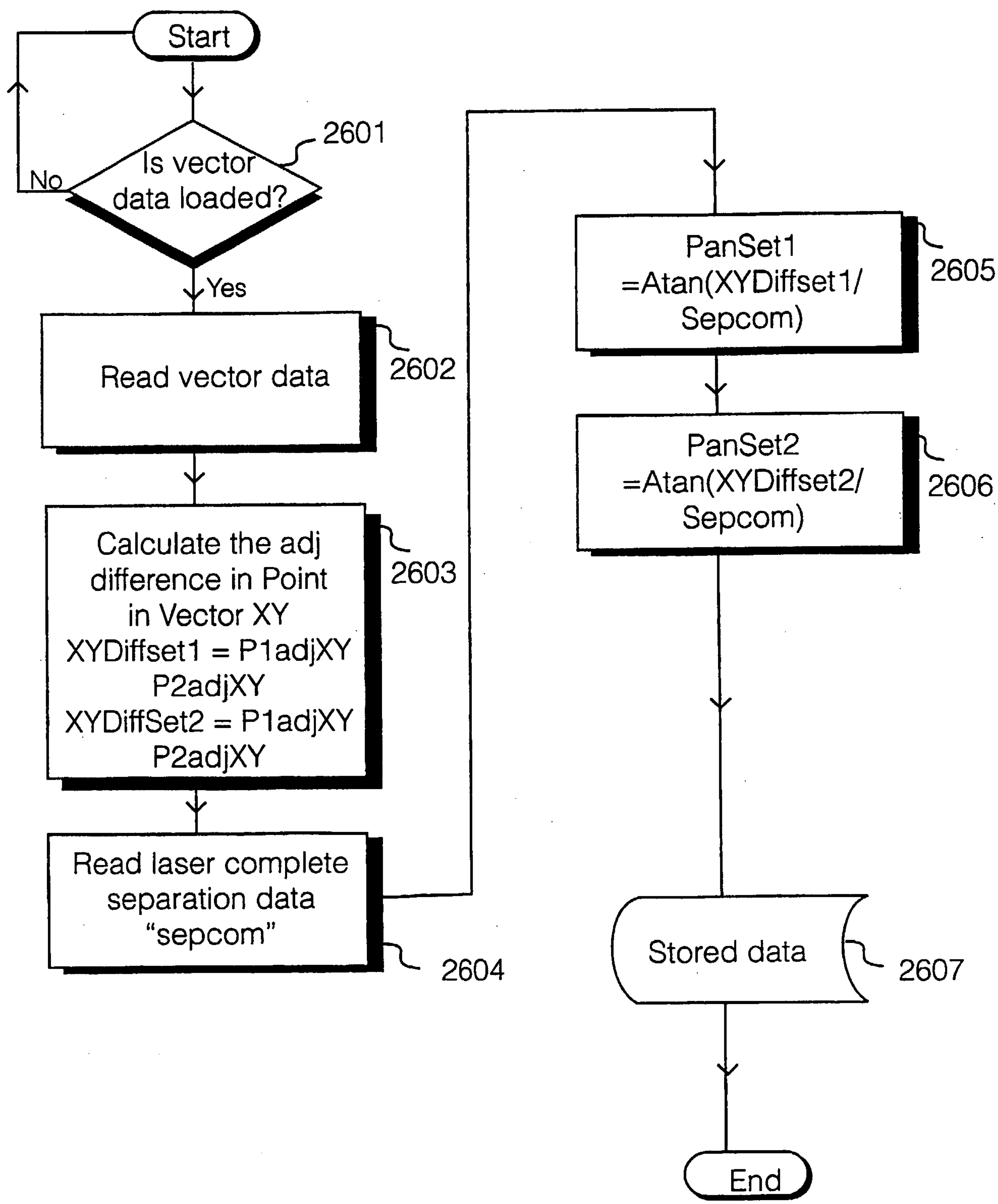

Start
Is vector data loaded?
No
Yes
2601
Read vector data
2602
Calculate the adj difference in Point in Vector XY
XYDiffset1 = P1adjXY P2adjXY
XYDiffSet2 = P1adjXY P2adjXY
2603
Read laser complete separation data "sepcom"
2604
PanSet1 =Atan(XYDiffset1/ Sepcom)
2605
PanSet2 =Atan(XYDiffset2/ Sepcom)
2606
Stored data
2607
End

Fig. 26

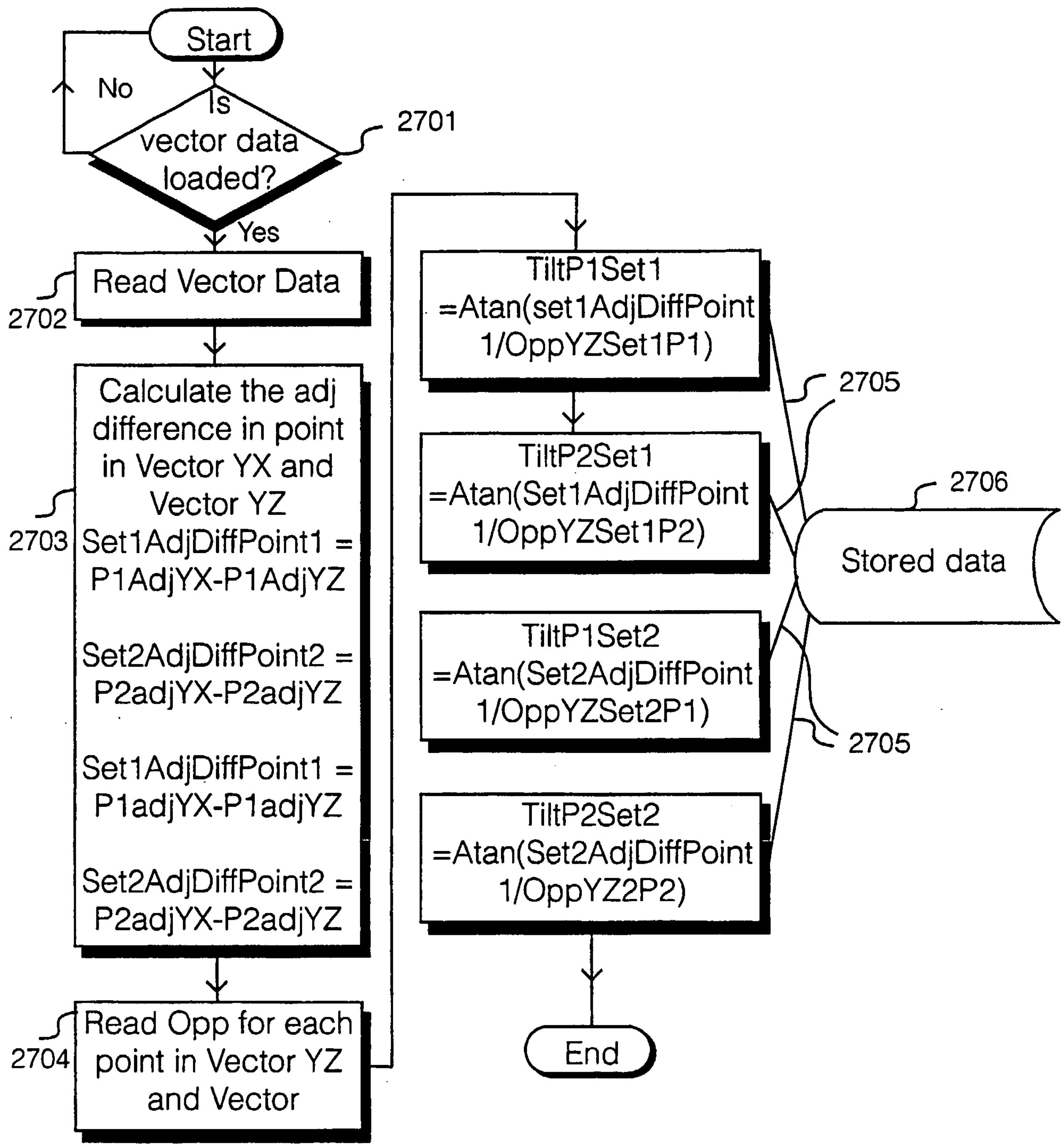

Start
No
Is vector data loaded?
2701
Yes
Read Vector Data
2702
Calculate the adj difference in point in Vector YX and Vector YZ
Set1AdjDiffPoint1 = P1AdjYX-P1AdjYZ
Set2AdjDiffPoint2 = P2adjYX-P2adjYZ
Set1AdjDiffPoint1 = P1adjYX-P1adjYZ
Set2AdjDiffPoint2 = P2adjYX-P2adjYZ
2703
Read Opp for each point in Vector YZ and Vector
2704
TiltP1Set1 =Atan(set1AdjDiffPoint 1/OppYZSet1P1)
TiltP2Set1 =Atan(Set1AdjDiffPoint 1/OppYZSet1P2)
TiltP1Set2 =Atan(Set2AdjDiffPoint 1/OppYZSet2P1)
TiltP2Set2 =Atan(Set2AdjDiffPoint 1/OppYZ2P2)
2705
2705
Stored data
2706
End

Fig. 27

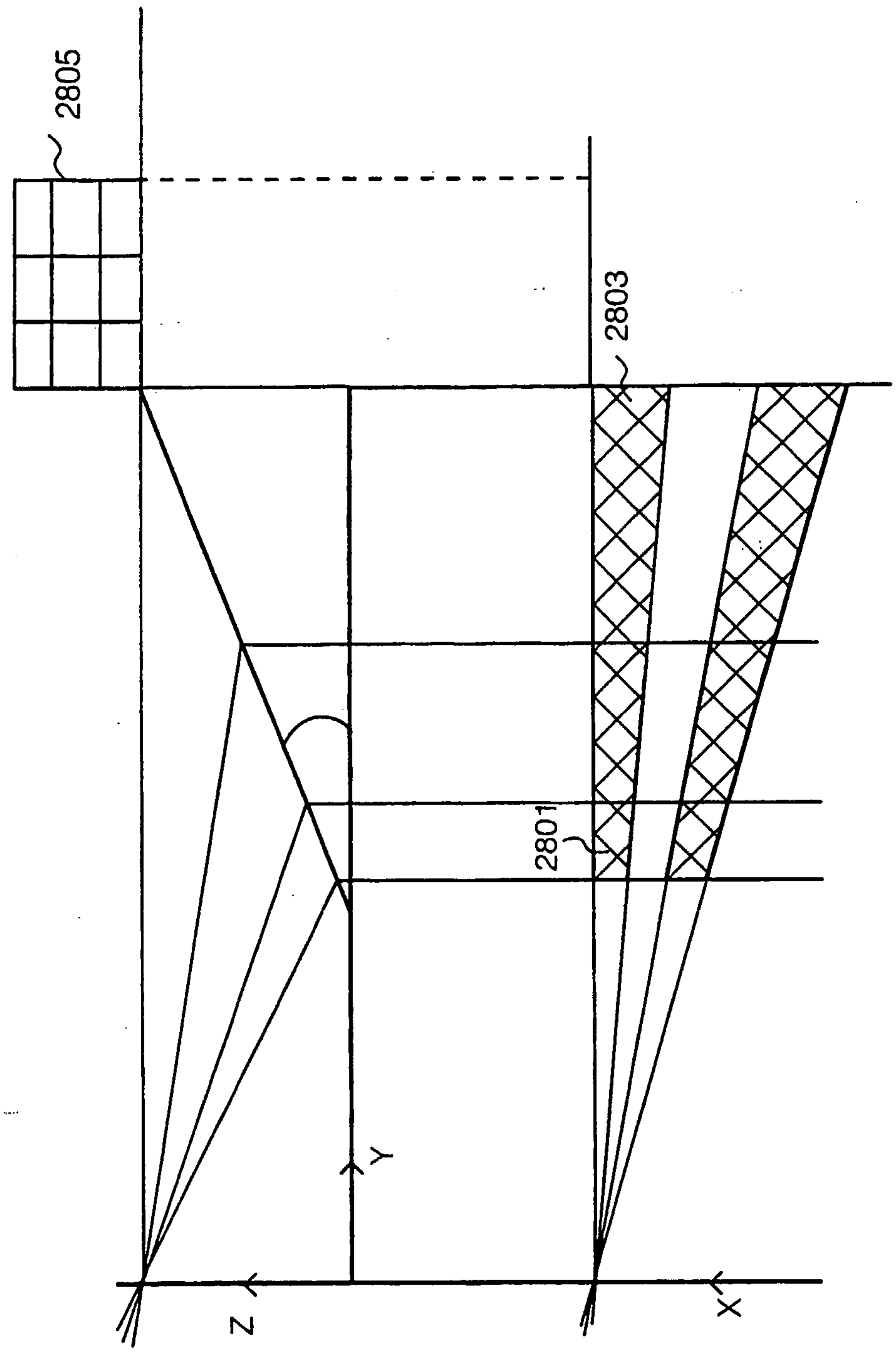


Fig. 28

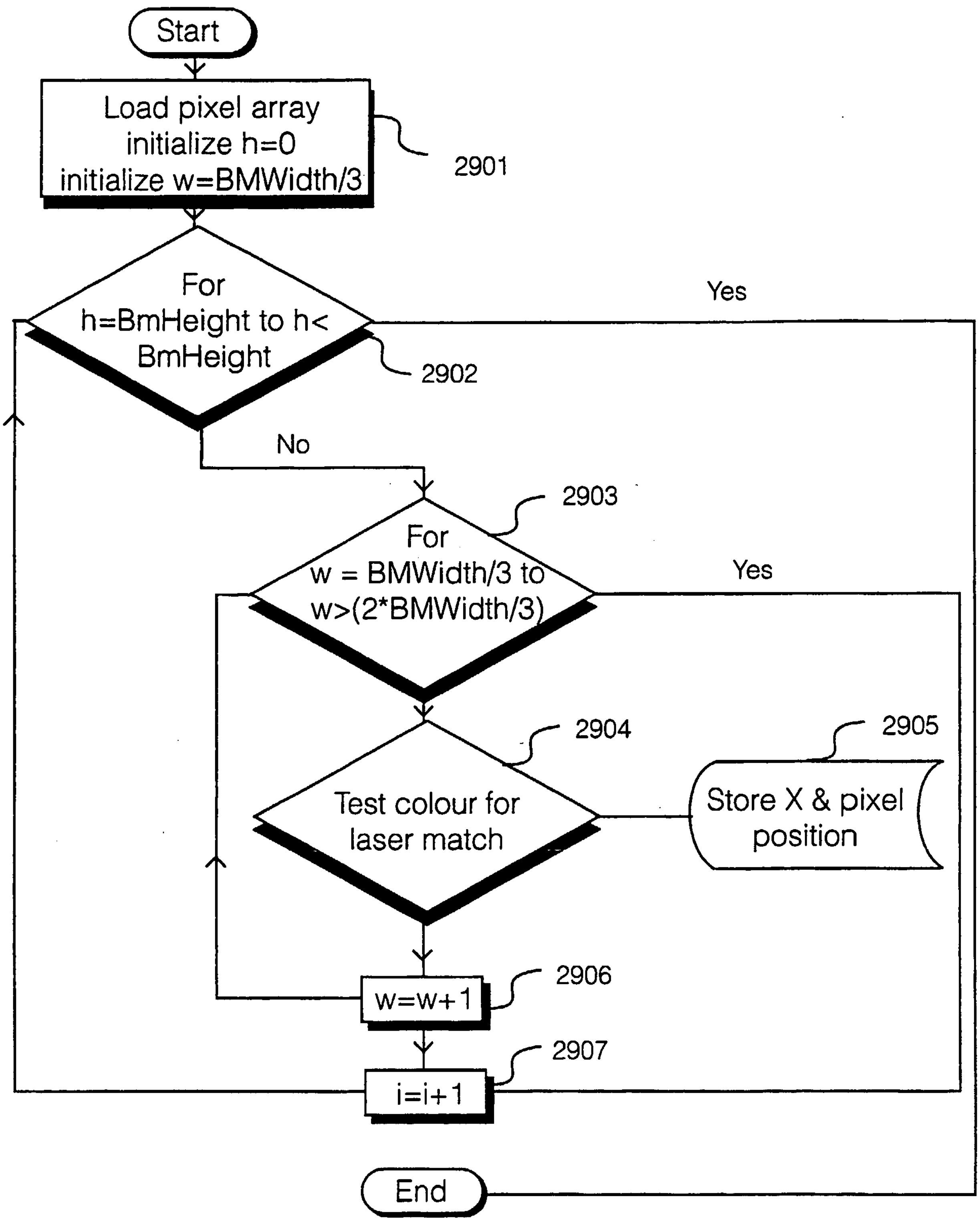

Start
Load pixel array
initialize h=0
initialize w=BMWidth/3
2901
For
h=BmHeight to h<
BmHeight
2902
Yes
No
2903
For
w = BMWidth/3 to
w>(2*BMWidth/3)
Yes
2904
Test colour for
laser match
2905
Store X & pixel
position
w=w+1
2906
i=i+1
2907
End

Fig. 29

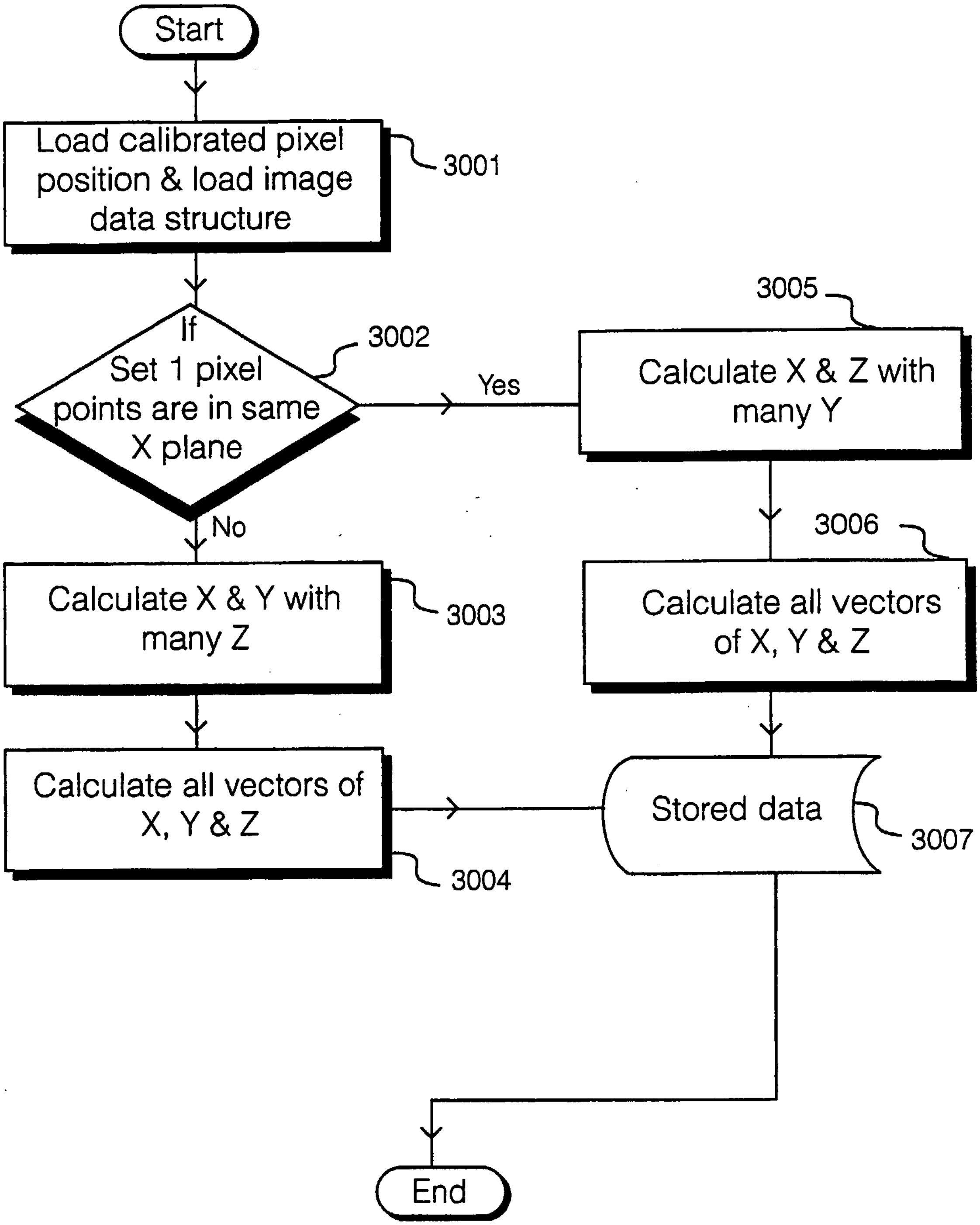
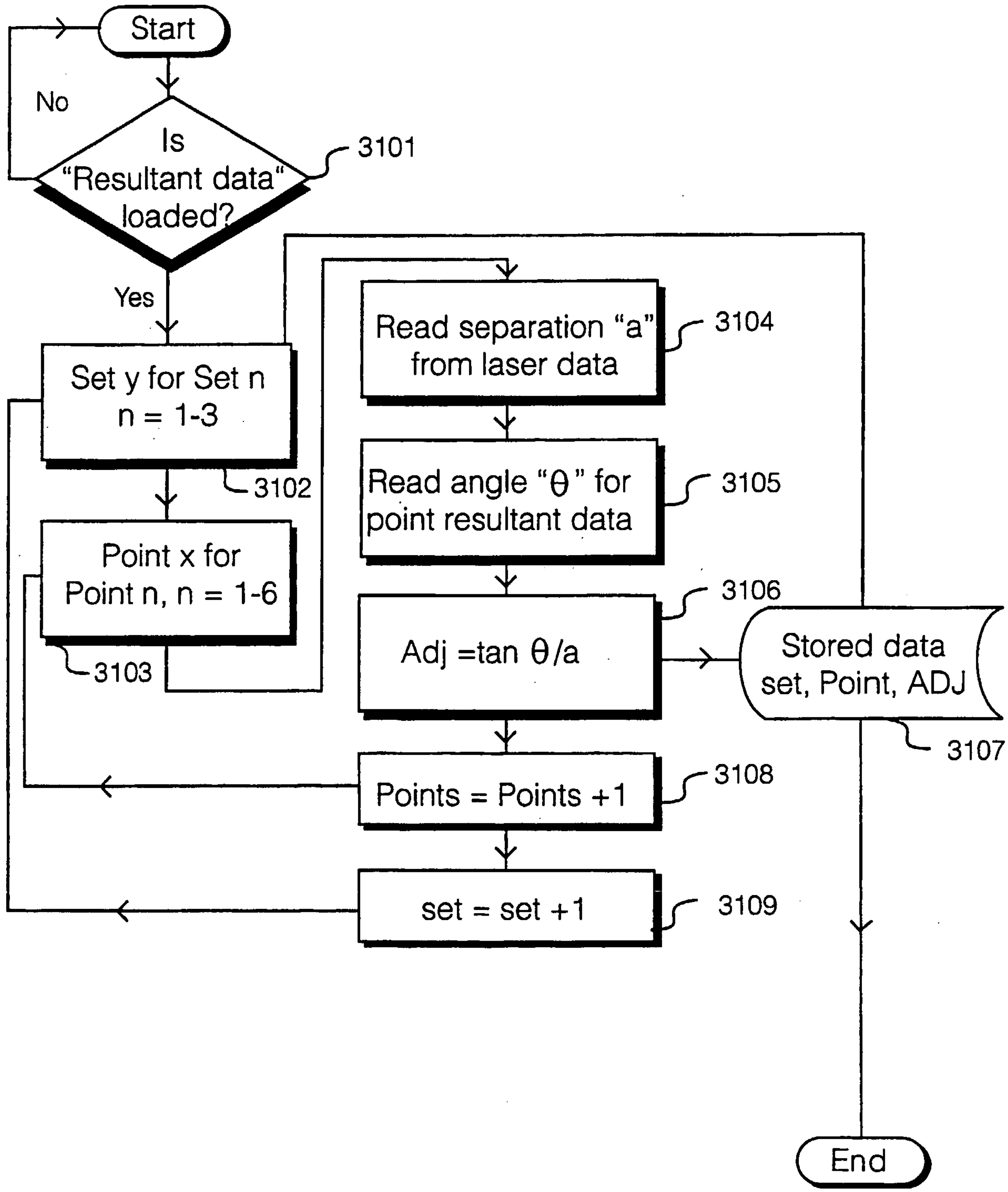

Start
Load calibrated pixel position & load image data structure
3001
If Set 1 pixel points are in same X plane
3002
Yes
No
Calculate X & Z with many Y
3005
Calculate all vectors of X, Y & Z
3006
Calculate X & Y with many Z
3003
Calculate all vectors of X, Y & Z
3004
Stored data
3007
End

Fig. 30



Start
No
Is "Resultant data" loaded?
3101
Yes
Set y for Set n
n = 1-3
3102
Point x for
Point n, n = 1-6
3103
Read separation "a" from laser data
3104
Read angle "θ" for point resultant data
3105
3106
Adj =tan θ/a
Stored data set, Point, ADJ
3107
Points = Points +1
3108
set = set +1
3109
End

Fig. 31

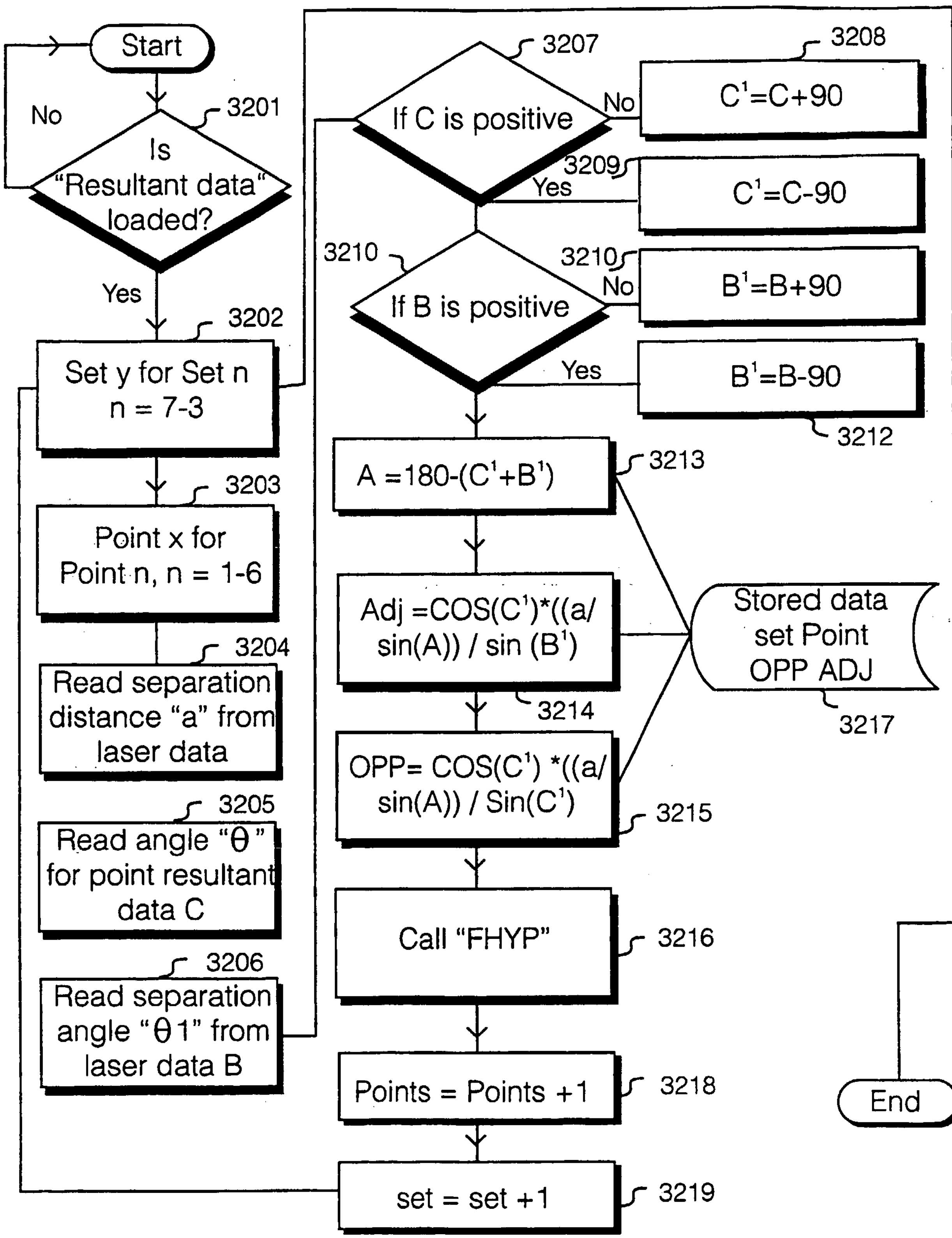
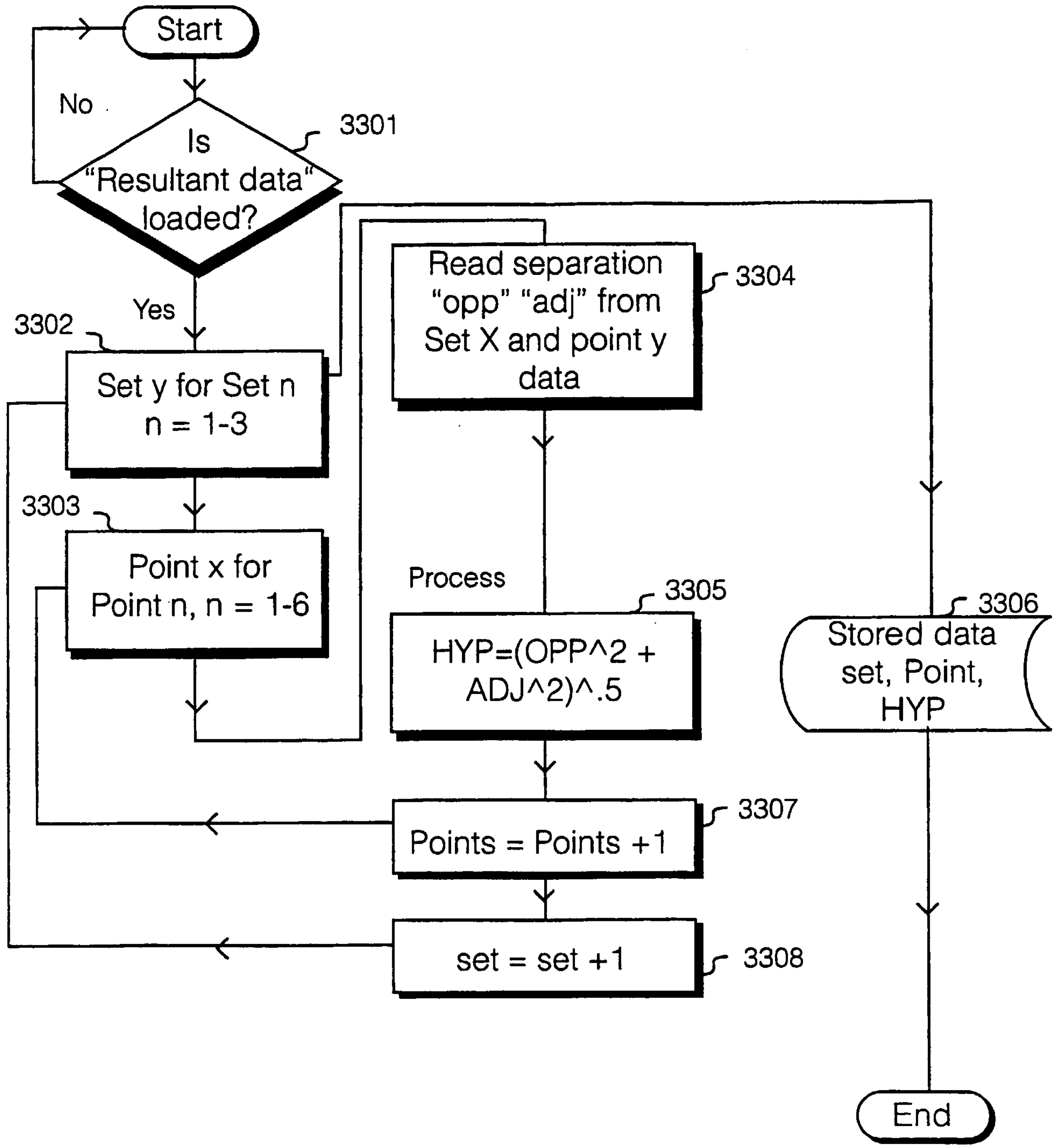

Start
No
Is "Resultant data" loaded?
3201
Yes
Set y for Set n
n = 7-3
3202
Point x for
Point n, n = 1-6
3203
Read separation distance "a" from laser data
3204
Read angle "θ" for point resultant data C
3205
Read separation angle "θ1" from laser data B
3206
If C is positive
3207
No
C'=C+90
3208
Yes
C'=C-90
3209
3210
If B is positive
3210
No
B'=B+90
Yes
B'=B-90
3212
A =180-(C'+B')
3213
Adj =COS(C')*((a/ sin(A)) / sin (B')
3214
OPP= COS(C') *((a/ sin(A)) / Sin(C')
3215
Stored data set Point OPP ADJ
3217
Call "FHYP"
3216
Points = Points +1
3218
set = set +1
3219
End

Fig. 32



Start
No
Is "Resultant data" loaded?
3301
Yes
3302
Set y for Set n n = 1-3
3303
Point x for Point n, n = 1-6
Read separation "opp" "adj" from Set X and point y data
3304
Process
3305
HYP=(OPP^2 + ADJ^2)^.5
3306
Stored data set, Point, HYP
3307
Points = Points +1
3308
set = set +1
End

Fig. 33

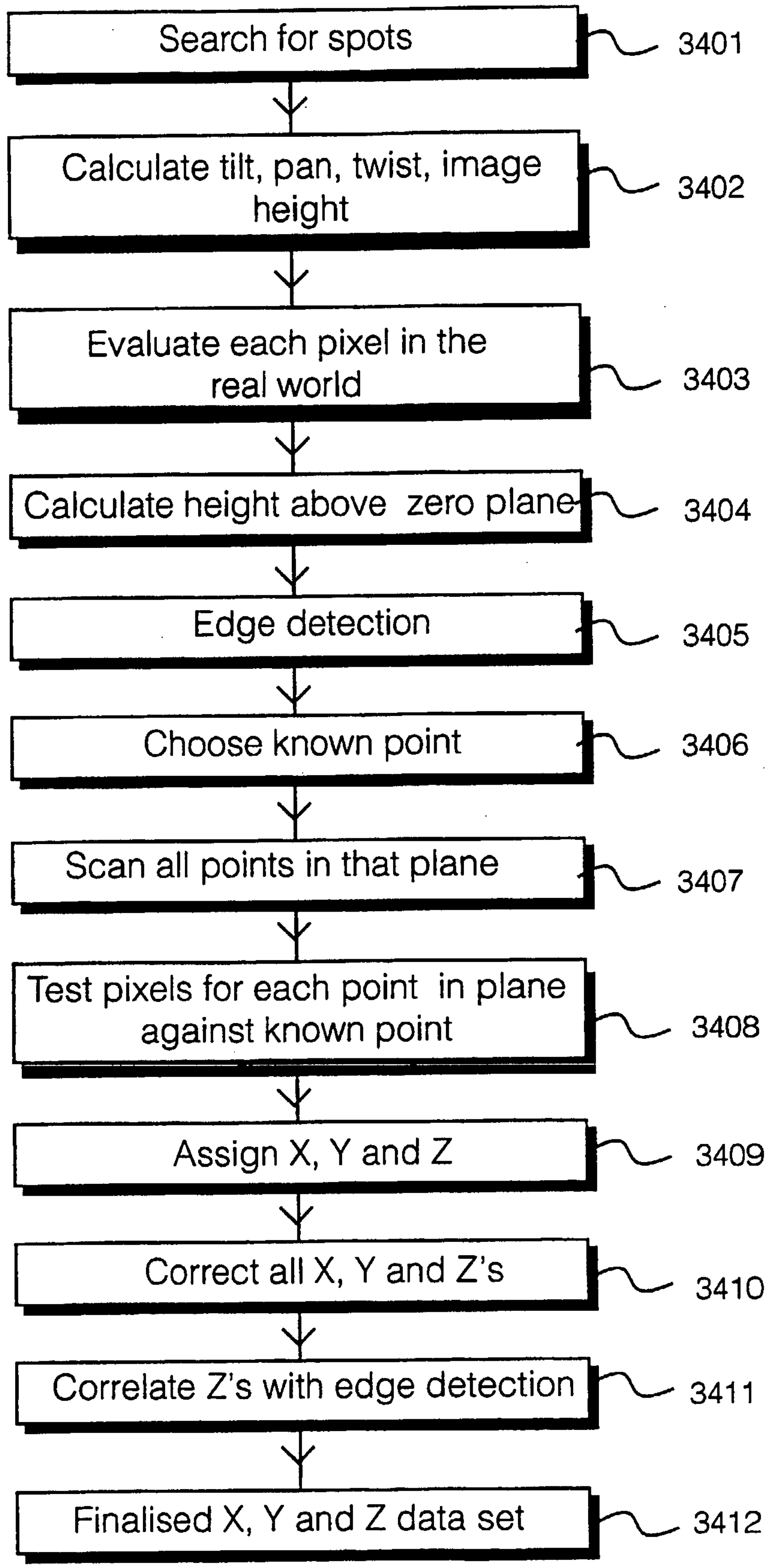

Search for spots
3401
Calculate tilt, pan, twist, image height
3402
Evaluate each pixel in the real world
3403
Calculate height above zero plane
3404
Edge detection
3405
Choose known point
3406
Scan all points in that plane
3407
Test pixels for each point in plane against known point
3408
Assign X, Y and Z
3409
Correct all X, Y and Z's
3410
Correlate Z's with edge detection
3411
Finalised X, Y and Z data set
3412

Fig. 34

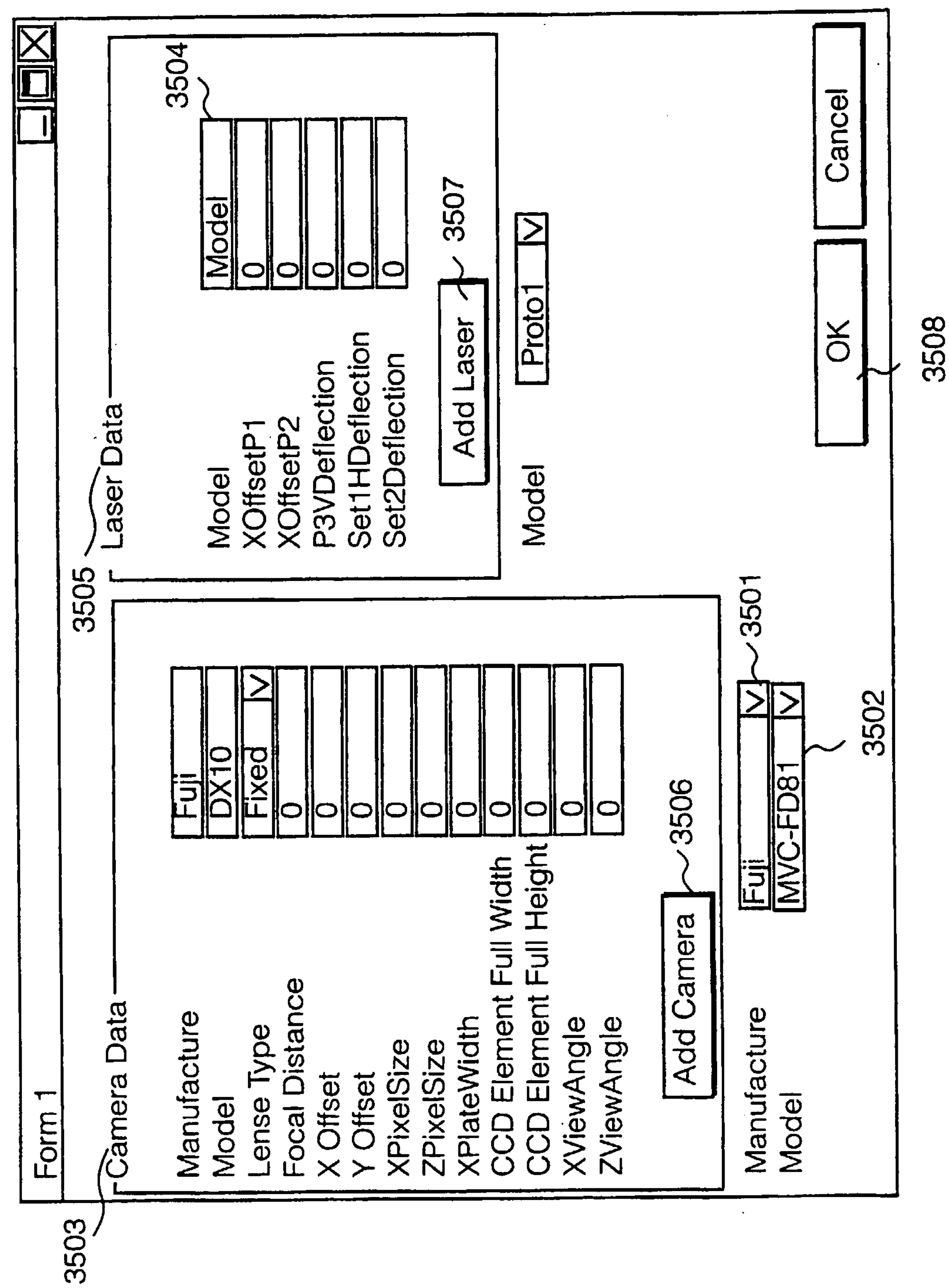

Form 1
Camera Data
Manufacture
Model
Lense Type
Focal Distance
X Offset
Y Offset
XPixelSize
ZPixelSize
XPlateWidth
CCD Element Full Width
CCD Element Full Height
XViewAngle
ZViewAngle
Fuji
DX10
Fixed
0
0
0
0
0
0
0
0
0
0
Add Camera
Manufacture
Model
Fuji
MVC-FD81
Laser Data
Model
XOffsetP1
XOffsetP2
P3VDeflection
Set1HDeflection
Set2Deflection
Model
0
0
0
0
0
Add Laser
Model
Proto1
OK
Cancel
3501
3502
3503
3504
3505
3506
3507
3508

Fig. 35

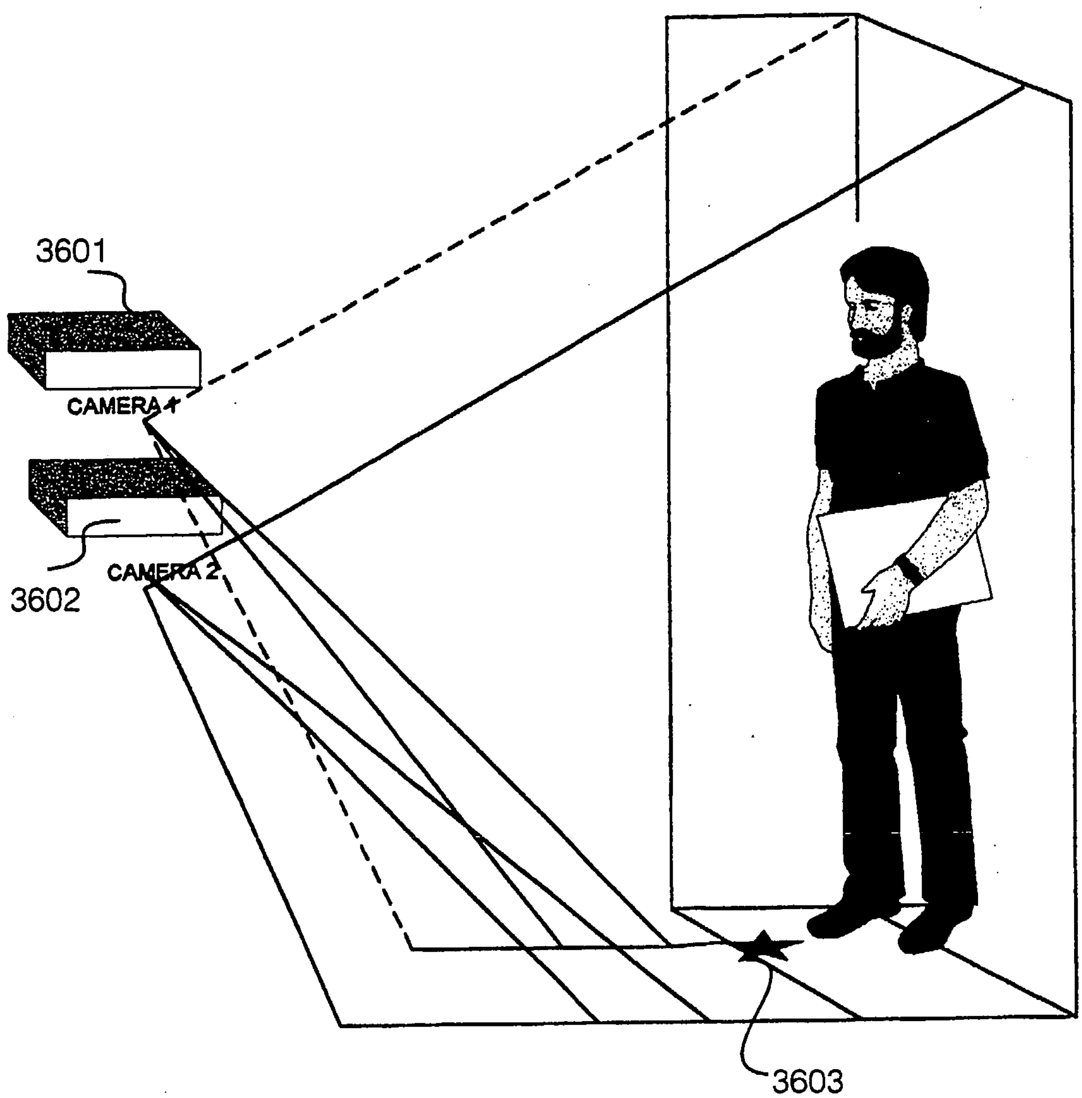


Fig. 36

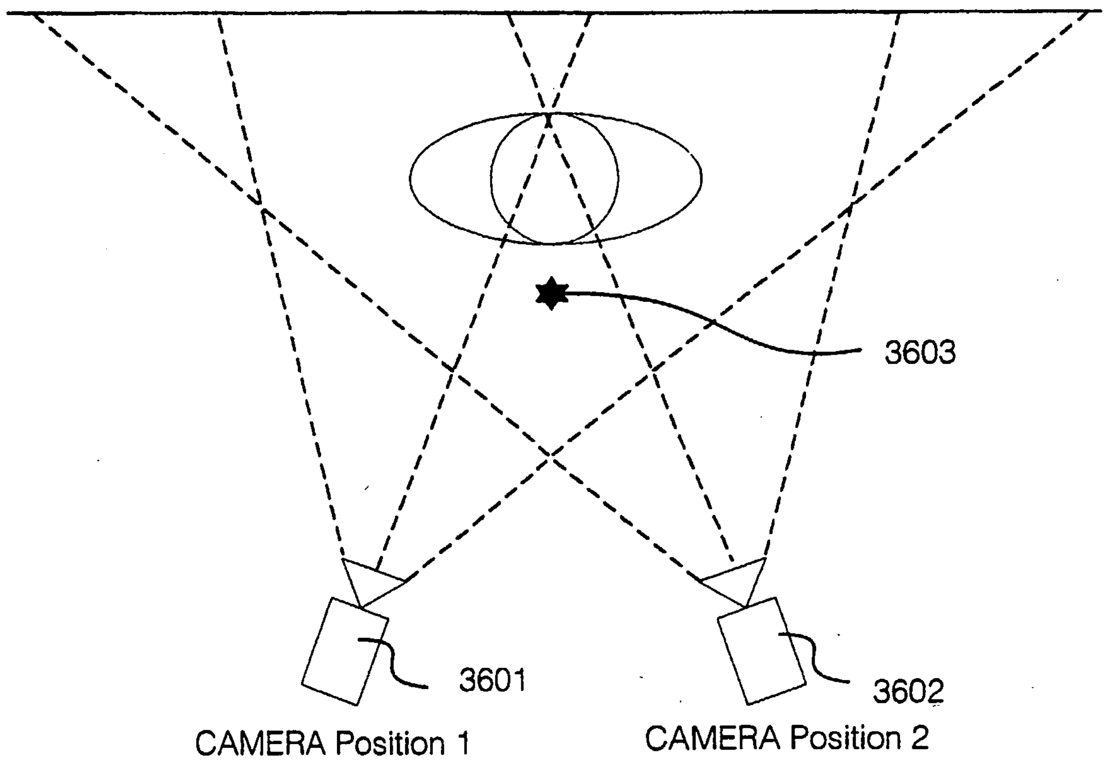


Fig. 37

2372656

APPARATUS AND METHOD FOR OBTAINING THREE-DIMENSIONAL POSITIONAL DATA FROM A TWO-DIMENSIONAL CAPTURED IMAGE

Field of the Invention

The present invention relates to apparatus and methods for determining multi-dimensional positional data from a two-dimensional image and particularly, although not exclusively, to apparatus and method for determining three-dimensional positional data from a two-dimensional captured image of a field of view comprising a plurality of optical markers.

Background to the Invention

Prior art cameras incorporate a light-sensitive media in the form of an insertable film on which the image captured by the camera is formed. As a general rule, the larger the film format, the finer the quality of image. Such films use a chemical process to form the image, the image being fixed onto a hard copy format e.g. paper. Such films produce an image as a gradient, the image not being formed by a number of identifiable and measurable image quanta. From this traditional chemical film format, semi-conductor arrays have been developed for capturing images via the sensing of light and production of a plurality of digitised signals. Examples of such digital image plates known in the prior art are the CCD (Charged Couple Device) and CMOS (Complementary MOS) arrays.

CCD and CMOS arrays comprise a plurality of photo-sensitive elements which each generate a pixel of data. Each pixel of data is then combined with adjacent pixels of data to produce an image of the entire field of view. Each pixel therefore has measurable physical dimensions which can be determined. These physical dimensions can be related to known positions in the field of view.

Prior art devices and methods have taken advantage of the CCD array to accurately measure distances between a digital camera and objects in a field of view. This type of range finding is illustrated in the following prior art documents:

- GB 2344012
- EP 0205175
- DE 4238891
- JP 07294216
- JP 08005370
- JP 08094324
- JP 09304055
- DE 19736588
- DE 29921143 U1
- DE 19949838
- JP 08285633
- JP 11094520
- JP 2000121354
- US 6,094,270

The above referenced prior art documents are concerned with measuring distances from an object to an image plate or lens including methods of eliminating information of low reliability.

In these prior art documents it is apparent that range finding has become possible using CCD image plates and a marker introduced to the field of view. The CCD then enables the pixel dimensions to be determined, and determining the characteristics of the markers introduced to the image enables trigonometrical surveys and Pythagoras calculations to obtain the distance from the image plate to the object in view.

EP 0205175 discloses the use of a plurality of cameras to obtain distance information relating a robot arm to an object. Determination of arm position is made as a relative determination between known points and does not provide information for all points in the field of view of one camera. Additionally, a plurality of cameras are required to provide image information in more than two dimensions.

US 6,094,270 is concerned with real time range finding. A sweeping light projection is required and an analysis of reflective light intensity is required to be adjusted to account for changes in reflectance characteristics of a surface dependent on the wavelength of incident light. It is necessary for a sweep of light to traverse the entire field of view to establish positional data about that field of view by a simple range finding to each point swept by the beam of light.

There is therefore a problem with apparatus and methods known in the prior art in that the prior art teaches that it is not possible to simply introduce a plurality of optical markers into a field of view, that field of view then being captured by an image plate, wherein the said optical markers have known optical characteristics, to obtain three-dimensional positional data about objects and surfaces (being points of reflectivity) in the field of view by an analysis of the two-dimensional captured image. The present invention solves this technical problem by providing technical apparatus and methods for the determination of three-dimensional positional data describing the position of regions of reflectivity in a two-dimensional captured image of a field of view.

Summary of the Invention

The inventors have realized that the projection of a plurality of markers having known characteristics can enable a two-dimensional image to be captured of the field of view including the projected markers such that a trigonometrical survey can be conducted to establish a set of image plate orientation values

enabling orientation of each pixel in a pixel array with respect to the real world regions of reflectivity in the field of view. This provides information about each pixel and the area of the real world field of view captured by the image to which each pixel is associated (the pixels worth). By applying a process of projective geometry, vector analysis and trigonometry to these orientation values three-dimensional positional data in respect of regions of reflectivity in the field of view can be established.

According to a first specific method of the present invention there is provided a method of obtaining multi-dimensional positional data from a field of view, said field of view containing a plurality of regions of reflectivity, said method comprising the steps of: projecting into said field of view a plurality of detectable markers, each marker produced by incidence of an electromagnetic beam on a region of reflectivity, wherein an angular relationship between said beams is known and a spatial relationship between the plurality of beams is also known at a source of said beams; and capturing a two-dimensional image of said field of view and said markers on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data; and identifying said markers in the captured image and using said known spatial and angular relationships to determine a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity.

Preferably, multi-dimensional comprises uni-dimensional, two-dimensional or three-dimensional.

Preferably, the spatial and angular relationship between said image plate and said sources is also known.

Preferably, said image plate comprises a CCD or CMOS array.

Preferably, said orientation values comprise the pan of said image plate with respect to regions of reflectivity in said field of view, the pan being the deviation of the image plate from an opposite parallel plane.

Preferably, said orientation values comprise the twist of said image plate with respect to regions of reflectivity in said field of view, the twist being the deviation of the image plate from an adjacent parallel plane.

Preferably, said orientation values comprise the tilt of said image plate with respect to regions of reflectivity in said field of view, the tilt being the deviation of the image plate from a plane at right angles to said image plate.

Preferably, said orientation values comprise at least one of the pan, twist, tilt and height of said image plate with respect to regions of reflectivity in said field of view.

Preferably, wherein said step of using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity comprises the steps of: using said orientation values to evaluate each pixel in the real world by determining the degree of pan and/or twist and/or tilt for each pixel; associating each said pixel of data with a said region of reflectivity and determining the real world position of said region of reflectivity.

Preferably, the method further comprises the step of: repeating said evaluation of each pixel for heights above a zero plane.

Preferably, the method further comprises the step of selecting a pixel having known three-dimensional positional data and scanning to all three-

dimensional planes to test that each pixel matches a set of three-dimensional co-ordinates.

Preferably, said step of using said orientation values to reconstruct a set of three-dimensional data describing the three-dimensional position of said regions of reflectivity further comprises the steps of: applying an edge detection function to the two-dimensional captured image; and checking the three-dimensional field data against the edge detection results to establish a finalised set of three-dimensional positional data describing the three-dimensional position of said regions of reflectivity.

Preferably, said step of identifying said markers in the captured image comprises the step of: conducting a search of the captured two-dimensional image to identify pixels receiving reflected light of a particular wavelength.

Preferably, said method further comprises the step of mapping the three-dimensional data obtained to reconstruct a virtual three-dimensional representation of the field of view.

Preferably, said optically detectable marker captured in said two-dimensional image is configured to cover an area of between one and four pixels on said image plate.

Preferably, said orientation values comprise one or more vector measurements of said regions of reflectivity.

Preferably there is provideda computer program product directly loadable into the internal memory of a digital computer comprising software code portions for performing the steps of: identifying said markers in the captured image and using said known spatial and angular relationships to calculate a set of

orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity; said steps according to the first specific method described herein.

Preferably, a computer program product directly loadable into the internal memory of a digital computer comprising software code portions for performing any of the steps according to the methods of the present invention.

According to a second specific method of the present invention there is provided a method of determining the distance between regions of reflectivity in a field of view and an image plate, said method comprising the steps of: projecting into said field of view at least one detectable marker, said marker produced by incidence of an electromagnetic beam on a region of reflectivity; wherein angular and spatial relationships between the source of said beam and said image plate are known; and capturing a two-dimensional image of said field of view and said markers on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data; and identifying said marker in the captured image and using said known spatial and angular relationships to determine a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and using said orientation values to determine the distance between said image plate and one or more of said regions of reflectivity.

According to a first aspect of the present invention there is provided apparatus for the projection of a plurality of detectable markers onto a field of view, wherein said markers are capturable as part of a two-dimensional image of said field of view formed on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data, said apparatus comprising: a projection unit comprising at least one electromagnetic radiation

source, said at least one source configured to produce a plurality of electromagnetic beams, each beam producing a said detectable marker on incidence with a region of reflectivity in said field of view, wherein an angular relationship between the projected beams is known, a spatial relationship between the plurality of beams is also known at a source of said beams; and mounting means configured to engage said projection unit; and said mounting means further comprising means to locate said image plate in a fixed spatial and angular orientation; wherein said projected beams are configured to project said markers onto said field of view to provide information for the analysis of a captured two-dimensional image of said field of view and markers in order to establish a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view, said orientation values enabling the reconstruction of multi-dimensional data describing the position of regions of reflectivity in said field of view.

Preferably, multi-dimensional comprises uni-dimensional, two-dimensional or three-dimensional.

Preferably, said image plate comprises a CCD or CMOS array.

Preferably, said image plate is comprised by a digital camera or scanner.

Preferably, said plurality of beams comprises at least four beams.

Preferably, said markers form a predefined pattern on said field of view.

Preferably, said electromagnetic radiation comprises radiation of a wavelength in the range 10^{-15} m to 10^{-6} m.

Preferably, said electromagnetic radiation comprises visible light of a wavelength of 635nm.

Preferably, said image plate is comprised by a digital camera, said mounting means configured to engage said digital camera for location of said digital camera in fixed spatial and angular orientation to said projection unit.

According to a second aspect of the present invention there is provided a device for projecting a plurality of markers onto a field of view, said markers capturable on an image plate comprising an array of elements each capable of generating a pixel of data, the captured two-dimensional image configured for the reconstruction of a set of multi-dimensional data describing the position of regions of reflectivity in said field of view from said captured two-dimensional image, said device comprising: at least one electromagnetic radiation source, said source configured to produce at least one electromagnetic radiation beam, said beam producing a said marker on incidence with a region of reflectivity in said field of view; and means to focus said beams; wherein an angular relationship between said beams and a spatial relationship between said sources is known, the markers thereby forming a predefined pattern in said field of view.

Preferably, said electromagnetic radiation source comprises at least one laser.

Preferably, said electromagnetic radiation source produces light of a wavelength in the range 10^{-15} m to 10^{-6} m.

Preferably, said electromagnetic radiation source produces visible light of a wavelength of 635nm.

Preferably, said image plate forms part of a digital camera.

Preferably there is provided a digital camera comprising a device according to the second aspect of the present invention wherein said image plate is formed by the image plate housed within said digital camera.

According to a third specific method of the present invention there is provided a method of determining a set of calibration values for an image plate comprising an array of elements each capable of generating a pixel of data, said image plate configured for use in capturing a two-dimensional image of a field of view comprising a plurality of markers, said set of calibration values enabling the determination of multi-dimensional positional data describing the position of regions of reflectivity in said field of view, said method comprising the steps of: locating an imaging device in a first fixing position, said imaging device housing said image plate; and capturing a two-dimensional image of a reference plane; wherein said image plate is substantially parallel to said reference plane.

Preferably, following capture of an image at a first fixing position, said imaging device is relocated in at least one second fixing position from which at least one second image is captured.

Preferably, said reference plane comprises a planar surface divided into a grid having known dimensions.

Preferably, said image plate comprises a CCD or CMOS array.

Preferably, said method further comprises the step of establishing a set of calibration values specific to said image plate.

Preferably, said set of calibration values comprise one or more values taken from the set of: **X**, **Y** and **Z** offsets of said image plate from the fixing

position; x, y pixel dimensions; focal length; image plate width and height; x and y image plate view angles.

According to a third aspect of the present invention there is provided apparatus for determining a set of calibration values for an image plate comprising an array of elements each capable of generating a pixel of data, said image plate configured for use in capturing a two-dimensional image of a field of view comprising a plurality of markers, said set of calibration values enabling the determination of multi-dimensional positional data describing the position of regions of reflectivity in said field of view, said apparatus comprising: means to locate an imaging device in at least one fixing position, said imaging device housing said image plate; and a reference plane located in said field of view.

Preferably, said reference plane comprises a planar surface substantially parallel to said image plate and further comprising a grid of known dimensions.

Preferably, said image plate comprises a CCD or CMOS array.

According to a fourth specific method of the present invention there is provided a method of using a single camera device to obtain three-dimensional positional data from a two-dimensional captured image, said two-dimensional captured image including a plurality of non-intrusive optical markers having known characteristics, said optical markers being capturable in a two-dimensional image of the field of view.

Brief Description of the Drawings

For a better understanding of the invention and to show how the same may be carried into effect, there will now be described by way of example only, specific embodiments, methods and processes according to the present invention with reference to the accompanying drawings in which:

Fig. 1 illustrates a diagrammatic representation of the apparatus used to capture a two-dimensional image and to analyse the captured image to obtain three-dimensional positional data.

Fig. 2A illustrates a first predefined pattern of optical markers.

Fig. 2B illustrates a second alternative predefined pattern of optical markers.

Fig. 3A illustrates in side view a diagrammatic representation of the projection of optical markers towards a plane.

Fig. 3B illustrates in diagrammatic representation a projection of beams to produce a plurality of optical markers at a plane.

Fig. 3C illustrates a pattern of optical markers produced at a plane.

Fig. 4 illustrates a diagrammatic representation of an image plate and projection unit projecting two light beams towards a surface for the production of optical markers and further illustrates reflection and image capture of the optical markers produced.

Fig. 5 illustrates a diagrammatic representation of an active image plate.

Fig. 6A and Fig. 6B illustrate two-dimensional representations of a virtual cone deriving the x and y pixel angle formed on the central axis between the focal point and a circle encompassing the image plate of an imaging device.

Fig. 7 illustrates a diagrammatic representation of an image plate and focal point.

Fig. 8 illustrates a diagrammatic representation of the view angle of the imaging device when tilted.

Fig. 9 is a diagrammatic representation of projected light beams towards a surface for the determination of distance between optical markers.

Fig. 10 illustrates an internal plan view and end elevation of a first embodiment of a projection unit.

Fig. 11 illustrates a plan view, end elevation and front elevation of a casing for a projection unit.

Fig. 12 illustrates a plan view and end elevation of a combined projection unit and camera apparatus.

Fig. 13A illustrates a side elevation of a mounting means.

Fig. 13B illustrates a front elevation of a mounting means.

Fig. 14 illustrates table 1 comprising a sample laser specification.

Fig. 15 illustrates a flow chart of the basic steps involved in obtaining three-dimensional positional field data.

Fig. 16 illustrates table 2 listing sample calibration information.

Fig. 17 illustrates a diagrammatic representation of the calibration apparatus and method.

Fig. 18 illustrates a first calibration flow chart for the determination of a set of calibration values.

Fig. 19 illustrates a second calibration flow chart for the determination of a set of calibration values.

Fig. 20A is a diagrammatic representation of twist.

Fig. 20B is a diagrammatic representation of tilt.

Fig. 20C is a diagrammatic representation of pan.

Fig. 21 illustrates a diagrammatic illustration to show the change in surface area that a pixel in an image plate represents with varying image plate orientation.

Fig. 22 illustrates a diagrammatic representation of the effect of light beams striking a ground plane to produce optical markers having pan and tilt and a reflection back to the image plate.

Fig. 23A, B and C indicate the angular and spatial measurements determined through vector analysis.

Fig. 24 illustrates a first flow diagram for the determination of a set of orientation values.

Fig. 25 illustrates a second flow diagram for the determination of a set of orientation values.

Fig. 26 illustrates a third flow diagram for the determination of a set of orientation values.

Fig. 27 illustrates a fourth flow diagram for the determination of a set of orientation values.

Fig. 28 illustrates in diagrammatic representation the effect of varying x, y and z on the representative object area associated with a single pixel.

Fig. 29 illustrates a flow diagram to determine the location of optical markers in a captured two-dimensional image.

Fig. 30 illustrates a first image analysis flow diagram.

Fig. 31 illustrates a second image analysis flow diagram.

Fig. 32 illustrates a third image analysis flow diagram.

Fig. 33 illustrates a fourth image analysis flow diagram.

Fig. 34 illustrates a flow diagram showing a summary scheme for the determination of a set of three-dimensional positional data.

Fig. 35 is an example of a screen showing calibration data.

Fig. 36 illustrates in diagrammatic representation the combination of captured images to cover a field of view larger than that in a single captured image.

Fig. 37 illustrates the combination of imaging devices to capture an extended field of view.

Detailed Description of the Best Mode for Carrying Out the Invention

There will now be described by way of example the best mode contemplated by the inventors for carrying out the invention. In the following description numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent however, to one skilled in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

The inventors have realized that two dimensional photographic images captured on an image plate, said image plate comprising an array of photosensitive elements, each element capable of generating a pixel of data, when combined with at least one marker introduced to the field of view, enables spatial and positional data of objects and surfaces in the field of view to be determined. In order to obtain this spatial and positional data it is necessary to obtain a representation of the image of the field of view on a quantized image plate comprising an array of said elements sensitive to the wavelength of the marker. This is necessary because the determination of spatial and positional data from said image is resultant on knowing information about the dimensions and optical characteristics of each pixel.

The inventors have realized that the introduction of a plurality of optical markers into a field of view, each marker produced by a beam of light or electromagnetic radiation incident on objects or surfaces being regions of reflectivity in said field of view coupled with knowledge of the spatial and angular relationships between said beams and the source of each beam, and further coupled with information relating the image plate on which an image of the field of view and said markers is captured, to the source of each beam, and applying a trigonometrical survey to establish a set of orientation values, enables image analysis of the captured two-dimensional image to produce a set of three-dimensional positional field data describing the three-dimensional position of each region of reflectivity in the field of view.

The present invention comprises apparatus for the projection of one or a plurality of optical markers required to obtain information about the field of view, apparatus for, and a method of, calibrating the image plate on which a two-dimensional image of the field view and projected markers is captured, and a method of determining three-dimensional positional data describing the three-dimensional position of regions of reflectivity in a field of view of the image plate.

The determination of three-dimensional positional data necessarily requires the determination of single dimension and two-dimensional data and the methods and apparatus of the present invention enable all such data to be determined.

Referring to Fig. 1 there is illustrated a field of view 101 being the area of a scene or landscape viewed and capturable by an image plate housed in an optical/imaging device 102, typically a digital camera. The field of view for instance could be a countryside landscape, a building site, products or parts and machinery forming part of a production line, people in a busy high street and generally any objects which can be viewed through an imaging device and captured on an image plate. Fig. 1 illustrates the apparatus required to obtain

information required to calculate three-dimensional positional data of regions of reflectivity within the field of view 101. A mounting means 104 is provided upon which imaging device 102 is engaged in fixed position. One method of engaging imaging device 102 upon the mounting means 104 is to make use of the tripod mounting on a digital camera. Mounting means 104 also provides means to locate a projection unit 103. Mounting means 104 is required to locate projection unit 103 and imaging device 102 in fixed, spatial and angular orientation to each other. Mounting means 104 may further be mounted on a tripod or provide for hand held operation of the combined imaging device, mounting means and projection unit 103.

Once an image has been captured, e.g. by taking a photograph, on the image plate of imaging device 102, said image comprising the field of view 101 and optical markers 107, this image is downloaded to a PC or laptop 108 where the two-dimensional captured image can be displayed 109 and analysed.

Projection unit 103 comprises at least one light source 105. Said at least one light source is configured to produce a plurality of beams of light 106. One or more beam splitters may be used. Upon incidence of each beam of light on a region of reflectivity in the field of view an optical marker 107, preferably a light spot is produced. Each light source is at a fixed spatial position which when projection 103 is fixedly mounted on mounting means 104, provides for each source to be in a fixed spatial position relative to imaging device 102 which is also mounted on the mounting means 104. The beams of light 106 are produced at fixed angular relationships to produce a pre-defined pattern of optical markers in the field of view.

The source of the light beam is required to be known such that fixed angular and spatial relationships can be calculated. Provided that the position of the light source itself and any lens means provided to focus the light beam are known, the

source can be considered as either the point at which the laser originates or the holographic or collimated or other lens used to focus the light beam. That is provided a plane of origin of the light/electromagnetic radiation beam can be determined, then this position can be considered the source of the beam having known fixed spatial and angular relationships to any other sources and to the image plate thereby enabling calculation of a set of orientation values and image analysis.

An example of 2 predefined patterns of optical markers is shown in Fig. 2 A and B. Figure 2A illustrates 6 optical markers, markers A and D, C and F approximately forming the corners of a rectangle and markers B and E being inwardly offset to the corners of the said rectangle towards A, D wherein B, E can potentially cross or overlap A, D. Fig. 2B illustrates an alternative arrangement of optical markers there being 5 markers arranged in a + shape. The invention is not limited by the shape formed by the optical markers but the fixed angular relationships between the beams producing each marker and the sources producing each beam is required to be known.

To obtain a full set of orientation values comprising height, pan, tilt, twist it is necessary to have a minimum of 4 optical markers. However, projecting a pair of markers provides sufficient information to calculate the tilt or pan, as well as the height and is thereby sufficient to give detailed and accurate two-dimensional positional data of all of the regions of reflectivity in the field of view. Projecting only a single optical marker provides sufficient information to obtain the orientation value of height of the image plate with respect to each region of reflectivity and thereby provides a distance or range finding function for each region of reflectivity in the field of view. The obtaining of a three-dimensional data set necessarily includes the determination of height and two-dimensional data; the method of determining a three-dimensional data set is described.

To obtain sufficient data to reconstruct a three-dimensional data set describing the position of regions of reflectivity in a field of view, a minimum of 4 optical markers are required. Each marker is produced from a single light beam incident on a region of reflectivity. A single light source may be split using a graticule or crystal into the requisite number of light beams.

It is possible to create a large single optical marker within the field of view. The resultant distortion of a single large optical marker can in effect be treated as though a plurality of markers are present formed by the differing extent of distortion at the edges of the marker. The use of such a single optical marker is in effect forming a plurality of optical markers which provide information from which a set of orientation values describing the orientation of the image plate to the regions of reflectivity in the field of view can be established.

Considering the rectangular configuration of markers illustrated in Fig. 2A projected into a field of view. Distortion of the projected rectangle into the field of view is a function of the effects of pan, tilt and twist of the image plate with respect to the regions of reflectivity in the field of view. These orientation values enable a set of orientation values describing the orientation of the image plate with respect to the regions of reflectivity in the field of view to be determined. Image analysis can then be conducted to establish multi-dimensional e.g. two dimensional or three dimensional positional field data.

Fig. 3B illustrates the path taken by each beam 106 to produce each optical marker 107 in the field of view 101. Fig. 3A shows a side on view of projection unit 103 projecting beams 106 onto a ground surface or plane 101. Fig. 3 B illustrates the projection of 6 beams 106 producing 6 optical markers A, B, C, D, E, F (107). Fig. 3 C illustrates the optical markers 107 as projected onto a field of view 101 (refer to Fig. 2A).

Fig. 4 illustrates a combined imaging and projection unit 401 housing an image plate 402 and projection unit 103. Fig. 4 provides an illustration of a schematic representation of the relationship between the image plate and projection unit. Light beams 106 are projected from light sources within projection unit 103 towards surfaces in field of view 101 of image plate 402. Regions of reflectivity in the field of view 101 reflect beams 106, reflective beams being captured on image plate 402. Regions of reflectivity within the field of view 101 are not required to be planar and may have dimensions in all 3 x, y and z axes.

In order to obtain three-dimensional positional data which describes regions of reflectivity in a field of view, each region of reflectivity being a point in the field of view which can be described in three dimensions, it is necessary to capture an image of that field of view with appropriate markers on a quantized image plate. Such a quantized image plate may comprise an image plate having an array of photo-sensitive elements, each element capable of generating a pixel of data. Imaging devices such as digital cameras and scanner's and digital video camera's are known which can acquire an image and convert that image to a plurality of digital signals. To do this it is known to form an image plate from a CCD (charged couple device) or CMOS (complimentary MOS) semi-conductor array comprising a plurality of photo-sensitive elements. In such an array each photosensitive element can produce a pixel of data by converting reflected light from a field of view into electrical energy. A CCD for instance converts incidental electromagnetic radiation e.g. light, which falls on the surface of the CCD into electronic signals which are then stored in a digital form in the camera's memory. Various types of array are available, one surface arrangement of a CCD is configured in the form of an array 1cm by 1cm (Bayer matrix) forming a grid of pixel's. The image plate array can be of any type provided it is an array comprised of materials sensitive to electromagnetic radiation and arranged as an array of individual cells. Importantly, the CCD is a photo-responsive media which

has measurable physical dimensions, including x, y and z physical dimensions. An image plate comprised by an array of pixel's therefore forms a two-dimensional image of a field of view which can be divided up into individual pixel's having physical dimensions which can be related to that field of view.

An imaging device such as a digital camera therefore has a plurality of optical characteristics including focal length, image plate dimensions and pixel dimensions. Fig. 5 illustrates a representation of an image plate 501 having an image plate height (Iy), an image plate width (Ix) and image plate diagonal (Id). For a 35 mm photo type format the relevant dimensions will be as follows:

- Ix = 36 mm
- Iy = 24 mm
- Id = 43.266615 mm

and

- $Id = (Ix^2 + Iy^2)^{1/2}$ Equation 1

Between the image plate and lens of a camera there is produced a virtual cone with a height equal to the focal length of the camera. Fig. 6A and Fig. 6B illustrate, as planar line drawings, representations of this cone wherein F = the focal point, the vertical distance between the image plate center and the focal point giving the focal length, f, 601.

Another representation of the relationship between view angle and image plate is shown in Fig. 7. The focal point F is located at the lens. Distance 601 between F and the center of the image plate being the focal distance, f, and the angle φ is the view angle. A relationship of the focal length to the angular field of view is given by the angle subtended at the lens with respect to a circle encompassing the image plate 502.

Fig. 8 illustrates a diagram showing the limit of the field of view which is determined by the angle of view φ. The limit of the field of view 806 is bisected by the center axis 805 of the image plate 803. A tilt angle 802 is defined between the center axis 805 and the strike plane 801. The field of view includes the ground plane 801 and the distance between the center of the image plate and the ground plane 801 is given by the height, h. If the physical dimensions of each pixel in the image plate are measured and the angular orientation of the image plate is known, each pixel can then be transposed to a reference plane, the ground plane, and each pixel row and the y plane of the image plate will then correspond to the position of the y co-ordinate of the image in the real world. In this way it is possible to determine the co-ordinates of optical markers 107 which may be introduced to the field of view.

Fig. 9 further illustrates this principal. Fig. 9 illustrates three planes, the image plane (I), a plane at which light is projected from a projection unit 103 (L) and an object plane being a plane in the field of view (O). Beams of light are produced at projection unit 103 projecting beams towards plane O to produce a plurality of optical markers 107. Knowing the spatial off-set of the projection unit light sources from the image plate I and knowing the angular relationship of beams projected from the projection unit a set of calibration values can be determined such that the angular relationship of the markers from the image plate can be calculated. In this way a normalization process can be carried out to allow orientation and imaging processes to consider each beam as though it had been projected from the image plate such that trigonometrical surveys can be conducted to find out spatial and positional data of regions of reflectivity in the object plane (O). Once the calibration process has been carried out (calibration process described below) and where information regarding pixel dimensions, image plate dimensions and the spatial and angular offsets of the light sources and projection unit 103 from the image plate are known such that distances a and b are known it is a matter of simple trigonometry to establish the distances (a + A)

and B. This information can be obtained due to the fact that each pixel has a measurable physical dimension which can be related to the position of markers in a field of view.

Fig. 9 is a simplistic representation to illustrate that distances between optical markers in a field of view e.g. distance B can be obtained. Typically, an image plate will not capture an image of a field of view that is planar or parallel to the image plate. As a result it is necessary to calculate a set of orientation values which describe the angles of approach of the image plate with respect to each region of reflectivity in relation to each of the three-dimensional axes. This allows for the image area occupied by each individual pixel to be analyzed by a trigonometrical survey of the relationship between the orientation values computed and the optical markers 107 introduced to the field of view which have known angular and relative spatial relationships. By performing a geometrical vector analysis, x, y and z values can be assigned to each region of reflectivity within the field of view.

Fig. 10 illustrates in plan view and in end elevation an internal arrangement of the projection unit 103. The projection unit 103 comprises a body 1001 housing at least one light source 1002, an aperture and lens means 1003 for focusing light produced by each light source 1002 lens means 1003 comprises a holographic lens 1005 and collimated lens 1004. Light source 1002 is preferably a laser e.g. diode laser providing a coherent light source. The purpose of the projection unit is to provide an array of light spots (the optical markers 107) into the field of view which can be captured by an associated imaging device. The relationships between the optical markers produced in the field of view are known as they relate to the source 1002 of each beam 106 in the projection unit. By placing the projection unit 103 in a mounting means 104 the spatial and angular relationship to the imaging device and the distance between the image plate and the projection unit 103 can be determined. The relationship between projection

unit and image plate can then be interpreted by the use of projective geometry, trigonometry and vector analysis to calculate a set of orientation values which describe the tilt, pan, twist and height of the image plate in relation to the plane on which a particular optical marker strikes a region of reflectivity in the field of view.

Fig. 11 shows an illustration of a plan view of a moulded case, showing an internal arrangement, for a projection unit illustrating a body 1001 and apertures and lens means 1003 for transmission of light beams. A front elevation of the case is also shown illustrating 3 apertures 1101 corresponding to aperture and lens means 1003 through which light beams can be emitted. Apertures 1102 provide for fastening means inserted to secure the projection unit together.

Lens and aperture means 1003 typically comprise a holographic 1005 and collimated 1004 lens for focusing of the light beam. The collimated lens has fixed optical characteristics which can be used to determine the divergence of the projected beam. Knowing the angular view of the associated imaging device and the divergence of light beams emitted from the projection unit it is possible to configure the optical markers 107 produced in the field of view to correspond to a required number of pixel's in the image plate. For instance it is preferable that one optical marker 107 is detected by only one pixel on the image plate.

The number of pixels that are covered by a single marker are dependent on a number of factors, eg the resolution of the image being taken, the distance of the image plate to the region of reflectivity (the marker), the height of the projection unit from the ground surface.

Fig. 12 illustrates a second embodiment of the projection unit 103. In this second embodiment the projection unit and imaging device are incorporated in a single unit. For instance, a digital camera may comprise an image plate formed

by a CCD array and at least one light source producing a plurality of light beams for projection into the field of view.

The combined imaging device and projection unit illustrated in Fig. 12 comprises a body 1201, at least one aperture and lens means 1204 for the transmission and projection of light beams produced by light source 1202, an image plate 1203 and camera lens arrangement 1205. Preferably the light source 1202 is a laser and the lens arrangement 1204 is a collimated holographic lens. Image plate 1203 is preferably a CCD or CMOS array.

Fig. 14 shows table 1, being a typical laser specification for use as the light source in either the first or second embodiment of the projection unit.

Fig. 13 A and Fig. 13 B illustrate one embodiment of the mounting means 104. In this mounting means 104 embodiment, a chassis 1301 is configured to receive a projection unit of the type illustrated in Figs. 10 and 11 in a recess 1302. Projection unit 103 is thereby securely engaged in recess 1302 to provide the projection unit in a fixed position. Electrical connection means 1303 are provided to connect a battery or mains power source 1304 to the projection unit located in recess 1302. A fixing screw 1305 is located on the chassis 1301 for location of an imaging device e.g. a digital camera in fixed spatial and angular orientation to the recess 1302 and thereby to a projection unit housed therein. A beveled knob 1306 is provided to engage fixing screw 1305 with the imaging means. Whilst mounting means 104 provides for a combination of a projection unit and imaging unit in a hand held manner a tripod fixing point 1307 is also provided if the user wishes to locate the apparatus in a fixed position.

The present invention comprises a method of obtaining three-dimensional positional data from a field of view. This method comprises the steps of capturing an image of a field of view, contained within the field of view are a plurality of

optically detectable markers projected by a projection unit as previously described. A two-dimensional image is captured on an image plate having an array of pixels. Knowing a set of calibration values a set of orientation values are determined which describe the orientation of the image plate with respect to the field of view. The orientation of each region of reflectivity in the field of view can then be determined and the image analysed by trigonometrical surveys, projective geometry and vector analysis to produce a three-dimensional data set describing the three-dimensional position of each region of reflectivity in the field of view.

The process of determining three-dimensional positional field data of regions of reflectivity in a field of view can be broken down into four basic steps as illustrated in Fig. 15. From a starting position 1501 a two-dimensional image has been captured which includes a plurality of optical markers 107. In order to calculate three-dimensional positional data of regions of reflectivity in the field of view it is necessary to know details of the image plate e.g. digital camera. Therefore a check for image plate details is made 1502. If no image plate details are held it is necessary to perform an image plate calibration procedure 1503 (see below). Once each calibration procedure has been completed image plate details are known and it is possible to progress to step 2.

Fig. 15 illustrates step 2 as a simplistic stepwise representation of a computer program for running step 2. Initially, a file is opened 1504 comprising relevant calibration values 1505 for the image plate. A search for the optical markers 1506 is conducted and once identified these calibration points are stored 1507.

Having identified calibration points it is possible to move onto step 3 wherein orientation values of the image plate with reference to the optical markers in the field of view 1508 are obtained, these orientation values then

being stored as data 1509. The orientation of the image plate to the plane of reflectivity captured by each pixel can then be evaluated and the orientation of the image plate with respect to the many planes that may exist in the field of view is determined to provide a set of orientation values.

Having determined a set of orientation values it is possible to move onto step 4 wherein the three-dimensional positions of the regions of reflectivity detected in the complete image array can be determined 1510 and this data stored 1511. This completes the image analysis to produce a three-dimensional data set describing three-dimensional positional data of regions of reflectivity.

As described for step 1 in Fig. 15 above it is necessary to determine a set of calibration values. Sample calibration values comprise the following:

- x, y and z offsets of each light source from the image plate, these offsets being the distance in each of the three-dimensional axes from the light source to the image plate;
- x and y pixel dimensions;
- angle of deviation of the image plate from the normal plane;
- Image plate width and height;
- x and y image plate view angles;
- Imaging device focal length.

This information is readily available from the manufacturer or handbook information supplied with most digital cameras. If the information is not available then it is necessary to carry out a calibration method to establish all of the details about the imaging device. These details can be stored in a data file. In this way, a software package may be provided having calibration values stored for a plurality of imaging devices e.g. several makes of digital camera. The user then simply selects the digital camera model which has been used to obtain the two-

dimensional image and the correct calibration values for a standard mounting means and projection unit are retrieved for use in the determination of orientation values and three-dimensional positional data of regions of reflectivity in the field of view (see Fig. 35).

Fig. 16 shows table 2 which illustrates a sample selection of commercial information available on purchasing a particular make of digital camera.

In order to obtain a set of calibration values a calibration method and calibration apparatus are required. Calibration apparatus comprises a jig of three upright fixing posts to which the imaging device, e.g. digital, camera is fixed and a planar panel forming a reference plane. A grid of 1cm squares is provided on the reference plane. The grid is generated by a set of lasers or alternatively is imprinted onto the panel forming the reference plane. The jig and reference plane are configured such that the image plate and reference plane are substantially parallel.

The method of calibration entails the fixing of the imaging device to the jig in a first position and capturing a two-dimensional image of the field of view comprising the reference plane.

Referring to Fig. 17 there is illustrated in schematic form the three fixing points 1701, 1702, 1703 on the jig. Image plate 1704 is offset 1705 to the center of each fixing point. The distance 1706 between fixing point 1703 and reference plane 1707 is measured for each fixing point. At each fixing point a plurality of images are captured e.g. ten images per fixing point.

The information then required to obtain the calibration values is specifically limited to design information of typical digital imaging devices, e.g. digital cameras and digital video cameras, as well as measurable offset distance 1706

of the imaging device to the reference plane. The imaging device data required for the calibration process are:

- Focal length of the camera;
- Camera photographic resolution (CCD plate size).

The photographic resolution is checked each time a photograph is analyzed and compared back against the camera model being used.

Figs. 18 and 19 show flow charts for the process of determining a set of calibration values. The processes illustrated are preferably implemented by a suitable software package. Each of the plurality of images taken at each fixing points 1701, 1702, 1703 is analysed 1801. A scale calculation is made relating the image to the fixing position relevant to the focal length 1802. A set of measurements are then taken from the image at predefined pixel positions 1803. From these measurements and the scale calculation a set of calibration values 1804 are determined. Sample calibration values comprising the following:

- The linear distance between the fixing tripod screw on the fixing point center and the image plate;
- x and y pixel dimensions;
- The offset distance of the center of the image plate to the height of the fixing point;
- The x displacement of the fixing point to the image plate;
- The photographic view angles;
- The full size of the active image plate array (image plate width and image plate height).

The next captured image is then loaded 1805 and the process repeated, data from the repeated calibration process being averaged 1806 to produce a set of calibration values.

Considering the user the method of calibration is simple. Initially, the imaging device, e.g. digital camera, is fixed to fixing point 1, 1701, the image plate is aligned parallel to the reference plane 1707. The photograph is taken (the image captured). This process is repeated a required number of times. The camera is then moved to fixing point 2, 1702, and the process is repeated. The camera is further moved to fixing point 3 and the process repeated again. Having captured all of the images from each fixing point the image files are copied to a PC and calibration software implementing Fig. 18 is run by the user and the average data stored as a set of calibration values. This process is illustrated in Fig. 19. The camera photographic resolution, R and size of array are loaded, 1901. Camera resolution is then set between R = 1 to n where n is the maximum resolution, 1902. This camera resolution is logged in step 1903. The calibration position (fixing point 1, 2 or 3) is recorded, 1904 and 1906. Two-dimensional images i = 1 to i = 10 are captured (1907, 1908, 1909). Image capture is repeated for the remaining calibration fixing positions (1910, 1905). Following image capture each calibration position process is repeated for resolutions R + 1 until R = n (1911). Having established a set of calibration values it is possible, knowing the x, y and z offset of the light sources in a projection unit relative to an image plate, to conduct an image analysis by implementing a set of orientation values to calculate spatial and positional data from an image captured with a plurality of optical markers produced by light beams from light sources in a projection unit associated with an image plate.

In this way calibration values for imaging devices, such as digital cameras, can be calculated. Each set of calibration values is specific to one specific image plate when used in conjunction with a specific projection unit and mounting

means. Ideally a selection of calibration values for different digital cameras is provided in a software package such that the user can tailor that package to the specific hardware used to capture the image. Calibration values can also take account of different projection units having different spatial and angular light beam projection values. Referring to Fig. 15, once a set of calibration values have been established the next step in determining three-dimensional positional data of regions of reflectivity in a field of view is to identify in the captured two-dimensional image the location of the at least one pixel within which the optical marker is located. Essentially, this is a search for laser points which can be carried out either manually wherein a two-dimensional image (e.g. BMP, JPEG, MPEG, GIF or other file type) is uploaded to a computer for viewing. Manual location of the points can be carried out by the user wherein the user identifies the optical markers within the two-dimensional captured image. Alternatively, an automatic search for the optical markers can be conducted searching the image for a particular wavelength of light, typically of a wavelength of 635nm. A Fourier transform or colour based search are alternative search methods. Once the location of all the optical markers has been identified within the two-dimensional captured image the orientation step (step 3 in Fig. 15) can be conducted.

Fig. 29 illustrates a process of searching for optical markers in a two-dimensional image of a field of view containing a plurality of optical markers in said field of view. A two-dimensional image is loaded from a pixel array 2901, a search of the image throughout it's height is performed 2902 and a search throughout the image width is performed 2903 until a colour match, typically for an optical marker of wavelength 635nm is obtained 2904. Having found a colour match, data relating the x and y position of the matched pixel is stored 2905. The search is then progressed in a spiral search pattern 2906 until all of the optical markers have been located and the appropriate data stored. The process is then repeated for the next image 2907.

As the method of determining three-dimensional positional data of regions of reflectivity in a field of view is reliant on the relationship between the physical dimension of individual pixels in an image plate and the area of real world image in the field of view covered by that pixel it is necessary, in order to obtain the three-dimensional positional data required, to perform an orientation step. The orientation step determines the amount of relevant orientation values of the camera image plate center when a particular captured image was obtained. The orientation values comprise the tilt, pan, twist and height of the image plate from the regions of reflectivity in the field of view when the image was captured.

The orientation values tilt, pan and twist have the following definitions with reference to Fig. 20 herein wherein 2001 represents a plane surface:

- Twist is the deviation of the image plate from an adjacent parallel plane as illustrated in Fig. 20A wherein C corresponds to the y axis entering the paper;
- Tilt is the deviation of the image plate from a plane which is at right angles to the image plate and corresponds to Fig. 20B wherein C corresponds to the x axis entering the paper;
- Pan is the deviation of the image plate from an opposite parallel plane wherein, in Fig. 20C, C corresponds to the z axis entering the paper.

Fig. 21 is a representative illustration of the effect of pan and tilt and the real world space which is absorbed by a single pixel. Angle 2101 is the tilt and angle 2102 is the pan of the image plate with respect to the plane of the field of view. It is readily noticeable that depending on the orientation of the image plate 2105 to the plane 2106 the area of plane absorbed by a single pixel (the pixels worth) differs depending on the orientation of image plate to the plane 2106. Reciprocating this arrangement for a fixed orientation of image plate with varying

tilt, pan and twist in the field of view, the area of real world space absorbed by a single pixel will vary with the orientation values which are therefore representative of a three-dimensional position of the regions of reflectivity in the field of view.

The input data required to calculate the degree of tilt, pan and twist of the image plate center when the photograph (image capture) was taken is as follows:

- Focal length of camera;
- x and y pixel dimensions;
- x and y pixel positions of the located optical markers in the image;
- x and y image resolution;
- Projection unit information e.g. angular relationship between beams and spatial relationships between beam sources, and relationship to image plate;

In particular conditions the input data further comprises input from the user to discriminate between the field of view of a vertical plane or a horizontal plane. In the general condition, the operator/user does not have to discriminate between vertical or horizontal planes.

The output data from the determination of orientation values is the:

- Tilt deviation of the camera to the plane;
- Pan deviation of the camera to the plane;
- The height of the camera to the image plate center;
- Twist deviation of the image plate;
- Center axis of the plane at which the markers strike.

Figs. 22 and 23A, B, C illustrate the effect of laser spots (optical markers) striking a ground plane in the field of view with a degree of pan and tilt applied

and the reflection back onto the image plate. Referring to Figs. 22 and 23A, B, C an example of the vector calculations to calculate the orientation of the image plate and projection unit are given below.

Orientation of Image Plate - Vector Calculations

<u>Key to Fig. 22</u>

2201	=	Tilt angle
2202	=	z Offset
2203	=	Set # C
2204	=	S1 Offset
2205	=	S2 Offset
2206	=	Pan angle
2207	=	P1 C Sep
2208	=	P3 C Sep
2209	=	P2 C Sep
2210	=	P1 Sep
2211	=	P2 Sep
2212	=	Image plate center axis

Sep	=	Separation
#	=	Set no. or Point no.
S	=	Set
P	=	Point
f	=	Focal length
l	=	Length

<u>Key to Fig. 23A</u>

2301	=	S# P# x or y
2302	=	f
2303	=	S# P# θ

<u>Key to Fig. 23B</u>

2304	=	S# P# l y_B
2305	=	S# Offset_C
2306	=	z Offset_A
2307	=	z Offset

2308 = S# P#_c

2309 = S# P#_b

Key to Fig. 23C

2310 = P# C Sep

2311 = S# P# x_Hyp

2312 = S# P# x_Adj

2313 = S# P# θ

Determine camera and projection unit light source relationship

P# C Sep = P# Sep + X Offset

Determine Angles S# P# θ for each point in each elevation

(See Fig. 23A)

For plan view Fig. 22

S# P# θ y = A Tan (S# P# y/f)

For side view Fig. 22

S# P# θ x = A Tan (S# P# x/f)

Determine associated length of light beams in plan elevation

(See Fig. 23B)

S# P# ly_C = S# Offset + 90

S# P# ly_B = S# P# θ - 90

S# P# ly_A = 180(S# P# ly_C + S# Offset_B)

S# P#_c = Sin (S# P# ly_C) * (z Offset/Sin (S# P# ly_A))

S# P#_b = Sin (S# P# ly_B) * (z Offset/Sin (S# P# ly_A))

Determine the center axis opposite and adjacent

S# P# y_Opp = Sin (S# P# θ y) ∗ S# P#_c

S# P# y_Adj = Cos (S# P# θ y) ∗S# P#_c

Determine associated length of light beams in side elevation

(See Fig. 23C)

S# P# x_Adj = P# C Sep/Tan (S# P# θ)

S# P# x_Hyp = P# C Sep/Sin (S# P# θ)

Determine Pan angle

<u>Set 1</u>

A = P1 C Sep + P2 C Sep

B = S1 P1_Adj + S1 P2_Adj

Pan = A Tan ($^A/_B$)

<u>Set 2</u>

A = P1 C Sep + P2 C Sep

B = S2 P1_Adj + S2 P2_Adj

Pan = A Tan ($^A/_B$)

Determine Tilt angle

A = S2 P1 y_Opp - S1 P1 y_Opp

B = S2 P1 y_Adj - S1 P1 y_Adj

Tilt = A Tan ($^A/_B$)

$A = S2\ P2\ y\_Opp - S1\ P2\ y\_Opp$

$B = S2\ P2\ y\_Adj - S1\ P2\ y\_Adj$

Tilt $= A\ Tan\ (^A/_B)$

Determine height

Center axis = Sin (S# C) ∗ (S# P#_c/ Sin (tilt))

V = Center axis ∗ Tan (tilt)

Height = Cos (Pan) ∗ V

Pixel number

Pi # C y = ((Res y / z) - Pi # y)

Pi # θ y = A Tan (Pi C y / f)

Determine center axis distance in y only

Pi # y_Adj = Height / tan (Pi # y_g)

Pi # y_Hyp = ((Pi # y_Adj) ^ 2 + (Height) ^ 2) ^ 0.5

Pi # y_c = Cos (Pi # y θ) ∗ Pi # y_Hyp

Determine all x values using center axis value in y and pan

Pi # C x = ((Res x / z) - Pi # x)

Pi # θ x = A Tan (Pi # C x / f)

Pi # x_g = 180 - (Pi # x θ + Pan)

For each Y Pi # y_c

For each Pi # x_g

Pi # x = Sin (IV Pan) ∗ (Pi # y_c / Sin (Pi # x_g))

Next Pi # x_g

Next Pi # y_c

Determine all the remaining Y values using the previously calculated values including pan

For each Pi # y θ

For Pi # x

Pi # x_adj = Cos (Pi # y θ) ∗ Pi # x

Pi # x_hyp = Pi # x_adj / Cos (Pi # y θ)

Pi # y_adj = Pi # x_hyp ∗ Cos (Pi # y_g)

Determine height of each point

Height Pi # x y = (Pi # x Hyp ^ 2 + Pi # y_Adj ^2) ^ 0.5

The above calculations are also suitable for matrix analysis.

Fig. 24 illustrates a flow chart describing the initial steps in determining a set of orientation values. Preferably, the steps of Figs. 24, 25, 26 and 27 are implemented by the running of a suitable software package on a personal computer. Referring to Fig. 24, a captured image of a field of view containing therein a plurality of optical markers produced by a projection unit 103 in conjunction with an associated image plate, e.g. a digital camera 102, is loaded in stage 2401. The image type is recognised as one of a set of formats e.g. of either a BMP, JPEG or GIF image file. If the image is not in a recognised image

format the message is invalid 2404. Once recognised as a valid image format file, a series of file data are assigned including file name, file header and details, image type, width, height, width in bytes, image planes and bits per pixel.

Referring to Fig. 25, once an image is loaded and recognised as described in Fig. 24 a check for the calibration values is made 2501, if the calibration values are present calibration data is read 2502 and the pixel positions are converted to millimeter measurements 2503, the resultant vectors of all the calibration points (optical markers) can be calculated 2504 and z and x world co-ordinates for each vector of all of the calibration points corresponding to the pan can be calculated 2505. zx world details corresponding to the tilt 2506 and twist 2507 of the calibration points are also calculated. Calibration point pan, tilt and twist data thus determined is stored 2508.

Referring to Fig. 26, if the vector data relating to pan, tilt and twist is loaded 2601 it is read 2602. For a projection unit having at least one light source projecting six beams as illustrated in Fig. 1 two sets of optical markers are produced in the field of view. Referring to Fig. 2A set 1 comprises optical markers A, B and C and set 2 comprises optical markers D, E and F. Within each set a plurality of points (corresponding to each optical marker) exists. A determination of the adjacent difference in points in terms of an xy vector is calculated in step 2603 and adjusting for the separation between light sources 2604 a set of values for pan deviation for set 1 and set 2 is determined (2605 and 2606) and this data is stored 2607.

Referring to Fig. 27 the calibration data is loaded 2701 and read 2702. The adjacent difference in point vectors yx and vectors yz is calculated 2703 and the opposite for each point in vector yz and vector yx is determined to establish a set of tilt values 2705 which are stored 2706.

The output of the orientation process described in Figs. 24 to 27 is the establishment of a set of orientation values describing the orientation of the image plate to the optical markers in the two-dimensional image of a field of view. Having established these orientation values it is now possible to orientate the entire pixel array with respect to all regions of reflectivity in the field of view in the real world with reference to the image plate. This provides information about each pixel and the area in the real world to which each pixel is associated (the pixel worth). Fig. 28 represents the real world area that a pixel 2805 represents in the two-dimensional captured image. With reference to Fig. 28 the following statements hold true:

Where the height varies and the plane in the field of view retains a constant tilt, pan and twist:

- As the image height grows in the z direction the area that a pixel represents in x and y increases (compare 2801and 2803);
- As the image height reduces in the z direction the area that a pixel represents in x and y decreases.

Where tilt varies and height, pan and twist remain constant:

- As the image tilt angle grows the area that a pixel represents in x and y increases;
- As the image tilt angle reduces the area that a pixel represents in x and y decreases.

Where pan varies and height, tilt and twist remain constant:

- If the pan angle is zero the distance in x and y remains constant for each y axis in x;

- As the pan angle is introduced the effect on the x and y distance varies;
  - If the pan angle is positive then the pixel worth to the left half increases and to the right decreases;
  - If the pan angle is negative then the pixel worth to the left half decreases and to the right increases.

The orientation of the entire pixel array in the real world with reference to the camera image plate corresponds with Fig.15 step 4 (1510).

Resultant stored data (2706, 2607, 2508) enables orientation of each pixel in the array with respect to the real world. In order to calculate three-dimensional positional data of regions of reflectivity in the field of view it now remains to conduct an image analysis to obtain the world x, y and z positions for each pixel in the image plate. Image analysis comprises the determination of the convergence of points or planes in the space domain. In order to conduct the image analysis the following data is established:

- x and y pixel dimensions;
- x and z pixel position;
- x and y image resolution;
- Tilt, pan and twist deviation of the image plate to the plane (there is twist in the vertical plane);
- Height of the camera (camera center axis) to the image plate center;
- File name.

Fig. 30 is a flow diagram illustrating the first steps in the image analysis. Calibrated pixel position and image data structure, including orientation values, is loaded 3001. The set 1 pixel points are checked 3002. If they are in the same x

plane then determination of x and z with many y's is made 3005 and all vectors of x, y and z are then determined 3006, this data being stored 3007. Where all set 1 pixel points are not in the same x plane the calculation of x and y with many z's is made 3003 to calculate all vectors of x, y and z 3004 which is stored as data 3007.

Referring to Fig. 31 a check is made to see whether the resultant data has been loaded 3101, where the resultant has been loaded for each set and each point (3102 and 3103) the separation of a pixel from an optical marker is read 3104 and an angle from the resultant data is also read. The adjacent is then calculated 3106 and stored as a data set comprising set number, point number and the corresponding adjacent 3107. This is repeated for all of the points on all of the sets (3108, 3109).

Fig. 32 illustrates a flow diagram of the next steps of the image analysis. Loading of the resultant data is checked 3201, then for each set 3202 and each point 3203 separation distance from the optical marker data is read 3204 and a corresponding angle for a first point resultant data and a second point resultant data 3206 is read, a trigonometrical survey is performed (3207 - 3212) to establish a resultant value 3213 from which an adjacent, opposite and HYP is established (3214 - 3216) which is stored as data set 3217. This is then repeated for all of the remaining points and sets 3218, 3219.

Referring to Fig. 33 illustrating further steps in the image analysis a check for resultant data loaded 3301 is made. Where resultant data has been loaded analysis of each set and each point (3302, 3303) is made in respect of reading the separation of opposite and adjacent from the chosen set and point (3304) and the HYP calculated 3305. The set point and HYP stored as data 3306. This is repeated for all points and all sets (3307, 3308).

The output data determined from the image analysis steps of Fig. 30 to 33 are as follows:

- A pixel array with corresponding world x positional data for each pixel in the captured image;
- A pixel array with all of the world y positional data for each pixel in the captured image;
- A pixel array with all the world z positional data for each pixel in the captured image.

The real world x, y and z co-ordinates can then be established for each pixel corresponding to the three-dimensional positional data of each region of reflectivity in the field of view captured on the image plate.

This real world x, y and z stored data is the primary data upon which a three-dimensional map/model of the captured image may be reconstructed. A further step in the image analysis process is to employ an edge detection module to systematically search the captured two-dimensional image for object and point edges in the captured image. The edge detection results can then be correlated with the world x, y and z positional data to provide a finalised x, y and z data set. This finalised x, y and z data set can then be used to reconstruct three-dimensional models of the regions of reflectivity in the captured image, that is to reconstruct a virtual three-dimensional model of objects and surfaces in the field of view.

The main steps in obtaining a three-dimensional positional data set of regions of reflectivity of a field of view starting with a captured two-dimensional image containing optical markers introduced to a field of view from a projection unit 103 where a set of calibration values have been determined are summarized in Fig. 34. Referring to Fig. 34, a search is made throughout the captured two-

dimensional image for each optical marker 3401, a determination of the orientation values of tilt, pan, twist and height are made 3402. Each pixel is then evaluated in real world terms by establishing orientation values for each pixel 3403. By correlation of a representation of the pixel area in the captured image with respect to the calculated orientation values the determination of height above a zero plane is made 3404. This may be coupled with an edge detection performed throughout the captured two-dimensional image 3405. A known point (e.g. an optical marker) is then chosen 3406. From said known point the two-dimensional captured image is scanned to all points in a corresponding x, y or z plane 3407 and each pixel in the image is correlated in the same chosen plane against said known point 3408. Step 3408 is repeated for all planes to assign x, y and z in the real world to each pixel 3409. An error correction process is then carried out to correct for errors in x, y and z axis 3410. The assigned z values are then correlated with the results of the edge detection to determine a finalized data set of said co-ordinates 3411 which are then reintroduced to formulate a finalized three-dimensional positional data field set describing regions of reflectivity in the field of view of an image plate which has captured the two-dimensional image analyzed. This finalised data set can then be used to produce a virtual map/model in three-dimensions of the field of view.

Fig. 35 illustrates a screen window of a software package for implementing the image analysis. The particular screen illustrated relates to the calibration values. Drop down menu 3501 provides the user with options to select one or more manufacturers of camera. The particular model can then be selected by selection of a serial number in drop down menu 3502. On the user selecting the correct manufacturer and model relating to the camera used to capture the image which is being analyzed, a set of previously determined calibration values is retrieved and displayed under the heading "Camera Data". A selection of the projection unit model is also made enabling retrieval of a predetermined set of calibration values for the projection unit which are displayed under the heading

"Laser Data" 3505. New camera and projection unit data can be added via input screens accessed through links 3506 and 3507. Once the user has chosen the correct data, the data entry is confirmed 3508.

Whilst the invention has been described in terms of capturing an image with an image plate comprising a plurality of pixels each capable of generating a pixel of data it is possible to primarily capture an image of a field of view with a plurality of optical markers 107 on a analogue type camera having a chemical based film format, said film format being of the type known in the prior art. A photographic image thereby obtained on hard copy e.g. paper can be transferred by means of a digital scanner into a data set comprising a plurality of pixels forming a two-dimensional image. By obtaining an equivalent set of calibration values relating the image plate to the projection unit used to obtain the image of the field of view and optical markers a set of orientation values can be ascertained to enable an image analysis as previously described to obtain a three-dimensional data set describing the three-dimensional positions of regions of reflectivity in the image captured.

The present invention described above therefore enables a three-dimensional map of the regions of reflectivity in a field of view to be reconstructed from a two-dimensional image of that field of view captured on an image plate. Each region of reflectivity corresponds to a point in the field of view from which light or other electromagnetic radiation is reflected. This reflected radiation can then be captured on the image plate. By obtaining positional data of these regions of reflectivity from a photographic image the ability to position accurately an object in the real world space from an image of that real world space is provided. Non-exhaustive examples of the applications of the present invention include the following:

- Surveying/mapping - an image of a building, or other area to be mapped, is captured on an image plate comprising a number of pixels where the image includes optical markers projected from a projection unit to enable rapid three-dimensional modeling and mapping. A single photograph can be taken and then either analysed on site by means of downloading to a laptop or sent back to head office via email for further analysis. Such analysis typically takes currently between 2 to 4 minutes to produce a three-dimensional model and with increasing processor speeds an instantaneous or real time application for onsite mapping is possible.

- Robotics - automated factory production lines commonly require positional data to locate one component with another. Where this is performed by automated robotic arms a rapid three-dimensional modeling is required to ensure proper location of components. Incorporating a camera into the robotic arms and an associated projection unit the required positional data can be determined in real time;

- Security - the invention has applications in tracking people and objects to monitor their location which includes security applications and monitoring of stock;

- Marketing - the present invention also has applications in the recognising of specific objects e.g. people, and may be applied to monitor the number of people moving through a space or attending a retail outlet and automatically log their movements;

- Real time video image modeling - the present invention is also compatible with image capture on a digital video camera wherein a real time three-dimensional video image can be reconstructed.

A further example of the applications of the present invention are illustrated by a further embodiment as follows. The projection of markers into a field of view is not limited to projection of visible light markers but includes markers produced by electromagnetic radiation beams extending throughout the electromagnetic spectrum from 10^{-15} meters to 10^{-6} meters. A particular example is the use of x-rays beams. Here, an x-ray source takes the place of the laser diode and one or more electromagnetic lens means is configured to focus each electromagnetic beam. One or more beam splitters may be included to produce a required number of markers. Considering the applications in the medical field. Projecting a plurality of electromagnetic beams towards a subject, e.g. a human body, with a back plate of lead, enables x-rays to be reflected from certain tissues through which the x-rays cannot penetrate. Such tissues typically comprise bone. In this embodiment the range of wavelength of electromagnetic radiation being used to produce the markers projected into the field of view must be compatible with the image plate such that the image plate is sensitive to that wavelength of electromagnetic radiation. By projecting a minimum of four x-ray markers, a model of the human body bone structure can be built up. By the use of appropriate radiation sensitive image plate arrays, focusing means and electromagnetic radiation sources, the principles of the present invention can be applied to electromagnetic radiation throughout the electromagnetic spectrum. Further potential uses of the present invention include thermal imaging using infra-red radiation and long distance mapping by the use of radio waves.

In a further embodiment of the present invention the inventors have understood the limits of utilizing a single imaging device. Any one imaging device has a maximum angle of view which determines the size of field of view. As a

result, large fields cannot be captured in a single image. To overcome this problem and to reconstruct detailed three-dimensional positional data of large fields of view it is necessary to take more than one image. This concept is illustrated in Figs. 36 and 37.

Referring to Fig. 36, a first image is captured at position 3601 and a second image is captured at position 3602. Each of the first and second images include a common reference point 3603, which may be externally introduced, reconstruction of three-dimensional positional data is as described above. Having produced a three-dimensional data set the common reference point 3603 enables the two reconstructed images to be aligned to provide a model of the combined field of view. This principle can be further expanded by capturing a plurality of images all having at least one common reference point enabling data from those images to be coordinated to produce a single data set for the combined field of view.

Fig. 37 is an optical illustration of Fig. 36 illustrating first camera 3601 and second camera 3602 each capturing images comprising at least one common reference point 3603. Data obtained from each captured image can be combined to produce a common three-dimensional positional data set to map regions of reflectivity in the combined field of view.

Therefore by having a plurality of imaging devices, e.g. digital cameras or digital video cameras, each camera positioned to capture overlapping fields of view with at least one adjacent camera wherein common reference points can be determined in each overlapping field of view, an area larger than the field of view of a single camera can be mapped. By transmitting information between camera databases, movement of an object in a particular area may be anticipated.

Claims:

1. A method of obtaining multi-dimensional positional data from a field of view, said field of view containing a plurality of regions of reflectivity, said method comprising the steps of:

projecting into said field of view a plurality of detectable markers, each marker produced by incidence of an electromagnetic beam on a region of reflectivity,

wherein an angular relationship between said beams is known and a spatial relationship between the plurality of beams is also known at a source of said beams; and

capturing a two-dimensional image of said field of view and said markers on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data; and

identifying said markers in the captured image and using said known spatial and angular relationships to determine a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and

using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity.

2. A method as claimed in claim 1, wherein multi-dimensional comprises uni-dimensional, two-dimensional or three-dimensional.

3. A method as claimed in claim 1 or claim 2, wherein the spatial and angular relationship between said image plate and said sources is also known.

4. A method as claimed in any of claims 1 to 3, wherein said image plate comprises a CCD or CMOS array.

5. A method as claimed in any of claims 1 to 4, wherein said orientation values comprise the pan of said image plate with respect to regions of reflectivity in said field of view, the pan being the deviation of the image plate from an opposite parallel plane.

6. A method as claimed in any of claims 1 to 5, wherein said orientation values comprise the twist of said image plate with respect to regions of reflectivity in said field of view, the twist being the deviation of the image plate from an adjacent parallel plane.

7. A method as claimed in any of claims 1 to 6, wherein said orientation values comprise the tilt of said image plate with respect to regions of reflectivity in said field of view, the tilt being the deviation of the image plate from a plane at right angles to said image plate.

8. A method as claimed in any previous claim, wherein said orientation values comprise at least one of the pan, twist, tilt and height of said image plate with respect to regions of reflectivity in said field of view.

9. The method as claimed in any of claims 1 to 8, wherein said step of using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity comprises the steps of:

using said orientation values to evaluate each pixel in the real world by determining the degree of pan and/or twist and/or tilt for each pixel;

associating each said pixel of data with a said region of reflectivity and determining the real world position of said region of reflectivity.

10. The method as claimed in claim 9, further comprising the step of:

repeating said evaluation of each pixel for heights above a zero plane.

11. The method as claimed in claim 9 or 10, further comprising the step of selecting a pixel having known three-dimensional positional data and scanning to all three-dimensional planes to test that each pixel matches a set of three-dimensional co-ordinates.

12. The method as claimed in any of claims 9 to 11, wherein said step of using said orientation values to reconstruct a set of three-dimensional data describing the three-dimensional position of said regions of reflectivity further comprises the steps of:

applying an edge detection function to the two-dimensional captured image; and

checking the three-dimensional data against the edge detection results to establish a finalised set of three-dimensional positional data describing the three-dimensional position of said regions of reflectivity.

13. The method as claimed in any previous claim, wherein said step of identifying said markers in the captured image comprises the step of:

conducting a search of the captured two-dimensional image to identify pixels receiving reflected radiation of a particular wavelength.

14. The method as claimed in any of claims 1 to 13, further comprising the step of mapping the three-dimensional data obtained to reconstruct a virtual three-dimensional representation of the field of view.

15. The method as claimed in any of claims 1 to 14, wherein a said detectable marker captured in said two-dimensional image is configured to cover an area of between one and four pixels on said image plate.

16. A method as claimed in any of claims 1 to 15, wherein said orientation values comprise one or more vector measurements of said regions of reflectivity.

17. A computer program product directly loadable into the internal memory of a digital computer comprising software code portions for performing the steps of:

identifying said markers in the captured image and using said known spatial and angular relationships to calculate a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and

using said orientation values to reconstruct a set of multi-dimensional data describing the position of said regions of reflectivity;

said steps as claimed in claim 1.

18. A computer program product directly loadable into the internal memory of a digital computer comprising software code portions for performing the steps of any of claims 9 to 14.

19. A method of determining the distance between regions of reflectivity in a field of view and an image plate, said method comprising the steps of:

projecting into said field of view at least one detectable marker, said marker produced by incidence of an electromagnetic beam on a region of reflectivity;

wherein angular and spatial relationships between the source of said beam and said image plate is known; and

capturing a two-dimensional image of said field of view and said marker on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data; and

identifying said marker in the captured image and using said known spatial and angular relationships to determine a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view; and

using said orientation values to determine the distance between said image plate and one or more of said regions of reflectivity.

20. Apparatus for the projection of a plurality of detectable markers onto a field of view, wherein said markers are capturable as part of a two-dimensional image of said field of view formed on an image plate, said image plate comprising an array of elements each capable of generating a pixel of data, said apparatus comprising:

a projection unit comprising at least one electromagnetic radiation source, said at least one source configured to produce a plurality of electromagnetic beams, each beam producing a said detectable marker on incidence with a

region of reflectivity in said field of view, wherein an angular relationship between the projected beams is known, a spatial relationship between the plurality of beams is also known at a source of said beams; and

mounting means configured to engage said projection unit;

said mounting means further comprising means to locate said image plate in a fixed spatial and angular orientation;

wherein said projected beams are configured to project said markers onto said field of view to provide information for the analysis of a captured two-dimensional image of said field of view and markers in order to establish a set of orientation values describing the orientation of said image plate to regions of reflectivity in said field of view, said orientation values enabling the reconstruction of multi-dimensional data describing the position of regions of reflectivity in said field of view.

21. Apparatus as claimed in claim 20, wherein multi-dimensional comprises uni-dimensional, two-dimensional or three-dimensional.

22. Apparatus as claimed in claim 20 or 21, wherein said image plate comprises a CCD or CMOS array.

23. Apparatus as claimed in any of claims 20 to 22, wherein said image plate is comprised by a digital camera or scanner.

25. Apparatus as claimed in any of claims 21 to 24, wherein said plurality of beams comprises at least four beams.

25. Apparatus as claimed in any of claims 20 to 24, wherein said markers form a predefined pattern on said field of view.

26. Apparatus as claimed in any of claims 20 to 25, wherein said electromagnetic radiation comprises radiation of a wavelength in the range 10^{-15} m to 10^{-6} m.

27. Apparatus as claimed in any of claims 20 to 25, wherein said electromagnetic radiation comprises visible light of a wavelength of 635nm.

28. Apparatus as claimed in any of claims 20 to 27, wherein said image plate is comprised by a digital camera, said mounting means configured to engage said digital camera for location of said digital camera in fixed spatial and angular orientation to said projection unit.

29. A device for projecting a plurality of markers onto a field of view, said markers capturable on an image plate comprising an array of elements each capable of generating a pixel of data, the captured two-dimensional image configured for the reconstruction of a set of multi-dimensional data describing the position of regions of reflectivity in said field of view from said captured two-dimensional image, said device comprising:

at least one electromagnetic radiation source, said source configured to produce at least one electromagnetic radiation beam, said beam producing a said marker on incidence with a region of reflectivity in said field of view; and

means to focus said beams;

wherein an angular relationship between said beams and a spatial relationship between said sources is known, the markers thereby forming a predefined pattern in said field of view.

30. A device as claimed in claim 29, wherein said electromagnetic radiation source comprises at least one laser.

31. A device as claimed in claim 29 or 30, wherein said electromagnetic radiation source produces light of a wavelength in the range 10^{-15} m to 10^{-6} m.

32. A device as claimed in claim 29 or 30, wherein said electromagnetic radiation source produces visible light of a wavelength of 635nm.

33. A device as claimed in any of claims 29 to 32, wherein said image plate forms part of a digital camera.

34. A digital camera comprising a device as claimed in any of claims 29 to 32 wherein said image plate is formed by the image plate housed within said digital camera.

35. A method of determining a set of calibration values for an image plate comprising an array of elements each capable of generating a pixel of data, said image plate configured for use in capturing a two-dimensional image of a field of view comprising a plurality of markers, said set of calibration values enabling the determination of multi-dimensional positional data describing the position of regions of reflectivity in said field of view, said method comprising the steps of:

locating an imaging device in a first fixing position, said imaging device housing said image plate; and

capturing a two-dimensional image of a reference plane;

wherein said image plate is substantially parallel to said reference plane.

36. The method as claimed in claim 35, wherein following capture of an image at a first fixing position, said imaging device is relocated in at least one second fixing position from which at least one second image is captured.

37. The method as claimed in claim 35 or 36, wherein said reference plane comprises a planar surface divided into a grid having known dimensions.

38. The method as claimed in any of claims 35 to 37, wherein said image plate comprises a CCD or CMOS array.

39. The method as claimed in any of claims 35 to 38, further comprising the step of establishing a set of calibration values specific to said image plate.

40. The method as claimed in claim 35, wherein said set of calibration values comprise one or more values taken from the set of:

X, **Y** and **Z** offsets of said image plate from the fixing position;

x, y pixel dimensions;

focal length;

image plate width and height;

x and y image plate view angles.

41. Apparatus for determining a set of calibration values for an image plate comprising an array of elements each capable of generating a pixel of data, said image plate configured for use in capturing a two-dimensional image of a field of view comprising a plurality of markers, said set of calibration values enabling the determination of multi-dimensional positional data describing the position of regions of reflectivity in said field of view, said apparatus comprising:

means to locate an imaging device in at least one fixing position, said imaging device housing said image plate; and

a reference plane located in said field of view.

42. Apparatus as claimed in claim 41, wherein said reference plane comprises a planar surface substantially parallel to said image plate and further comprising a grid of known dimensions.

43. Apparatus as claimed in any of claims 41 or 42, wherein said image plate comprises a CCD or CMOS array.

44. The method of using a single camera device to obtain three-dimensional positional data from a two-dimensional captured image, said two-dimensional captured image including a plurality of non-intrusive optical markers having known characteristics, said optical markers being capturable in a two-dimensional image of the field of view.

The Patent Office — Patents • Designs • Copyright • Trade Marks

60

INVESTOR IN PEOPLE

Application No:	GB 0104456.9	**Examiner:**	Dr E.P. Plummer
Claims searched:	1 to 28	**Date of search:**	12 November 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4D (DLM, DLAT, DLRA, DLPC, DLPX); G1A (AAJL)

Int Cl (Ed.7): G01S 17/46, 7/491, G01C 3/08, 10

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP0145957A1	Zeiss whole document & US4660970	1 to 8, 13, 18 to 28
A	EP0224237A1	Alcatel	
A	US5915033	Fuji	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- [x] BLACK BORDERS
- [x] IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- [x] FADED TEXT OR DRAWING
- [ ] BLURRED OR ILLEGIBLE TEXT OR DRAWING
- [ ] SKEWED/SLANTED IMAGES
- [x] COLOR OR BLACK AND WHITE PHOTOGRAPHS
- [ ] GRAY SCALE DOCUMENTS
- [ ] LINES OR MARKS ON ORIGINAL DOCUMENT
- [ ] REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- [ ] OTHER: ____________________

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.